METALLURGIA

THE BRITISH JOURNAL OF METALS

Vol. 59 No. 355 MAY, 1959 Monthly: Two Shillings and Sixpence

Nu-way

presents

ROTAVAC P.R.N. SERIES

proportioning oil burners

Advantages

1 ONE LEVER controls both oil and air, keeping the ratio constant from maximum to minimum firing rate. Easily and efficiently operated by unskilled labour.

2 RADIAL MOVEMENT allows burner to be easily controlled in groups on one furnace instantly and accurately by shaft or cable. Manual or automatic control.

3 QUICK-RELEASE inner assembly makes nozzle cleaning a simple operation. Patent withdrawal latch overcomes sticky fuel oils.

4 ANY FURNACE ATMOSPHERE selected as will and maintained throughout firing range with uniformly high CO_2. Often gives reduced fuel consumption of 10-30% when replacing ordinary burners in particular applications.

5 VARIABLE AIR/OIL VALVE COUPLING allows selection of the correct air/oil ratio while the burner is running. Any ratio once selected remains constant from high to low flame. For extra-low flame see below.

6 EXTRA-LOW FLAME SHIELD provides reduced air pressure to give a smaller stable low flame for special applications.

7 REGULATING SLEEVE allows adjustment of flame shape while the burner is in operation.

8 ISOLATOR VALVE shuts off air supply when servicing the burner. An intermediate setting gives reduced air pressure for quicker simpler lighting.

MODELS

PRN. 1 cap. 3½ Imp. gals/hr.
PRN. 2 cap. 6 Imp. gals/hr.

PRN. 3 (Available shortly).
PRN. 4 cap. 20 Imp. gals/hr.

Particulars from

NU-WAY HEATING PLANTS LTD. (BOX A438) DROITWICH

and at LONDON, MANCHESTER, NEWCASTLE, GLASGOW, BELFAST, DUBLIN, BRISTOL

MAGNESIUM is the light answer

What have a motor car, a camera, a typewriter in common?
These and countless other products embody
pressure die castings made with Elektron magnesium.
Magnesium is increasingly chosen for pressure die castings
when lightness and a high strength/weight ratio are required.
Dimensional accuracy is high and the surface finish excellent.
The metal's good machinability at high speeds, generally without cutting fluid,
offers obvious economies in production time and costs.
Since pioneering the light alloy pressure die casting process
in this country, Birmal have developed foundry facilities
and techniques unsurpassed throughout Britain. You'll profit
by coming to us for the *light* answer to your casting problem.

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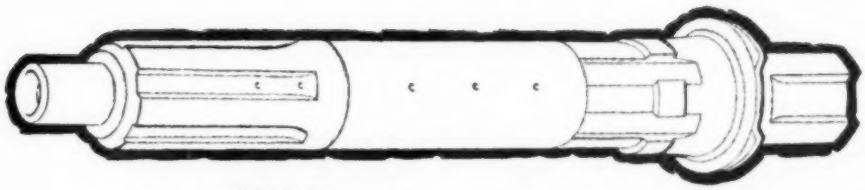
Birmingham Aluminium Casting (1903) Co Ltd Smethwick 40 Staffs



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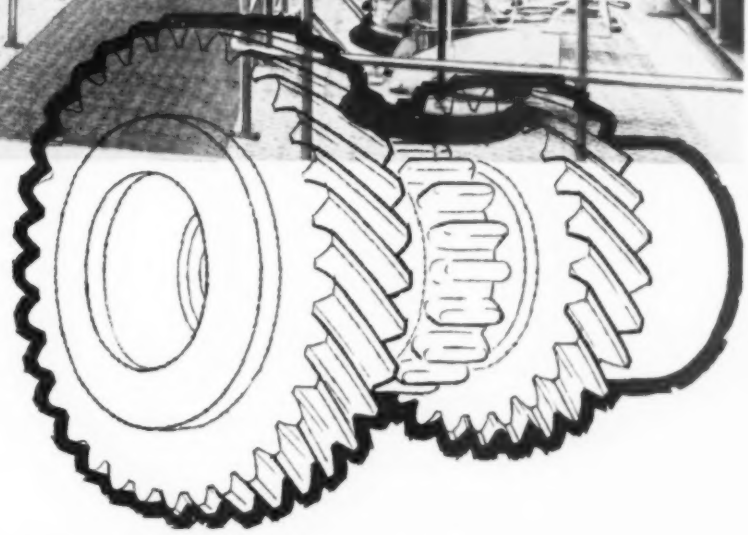

The Wild-Barfield Generated Gas and 'Carbodrip' methods of gas carburising ensure minimum carburising time, fastest production rates and full quality control. Write to us for advice on the application of gas carburising for your work.

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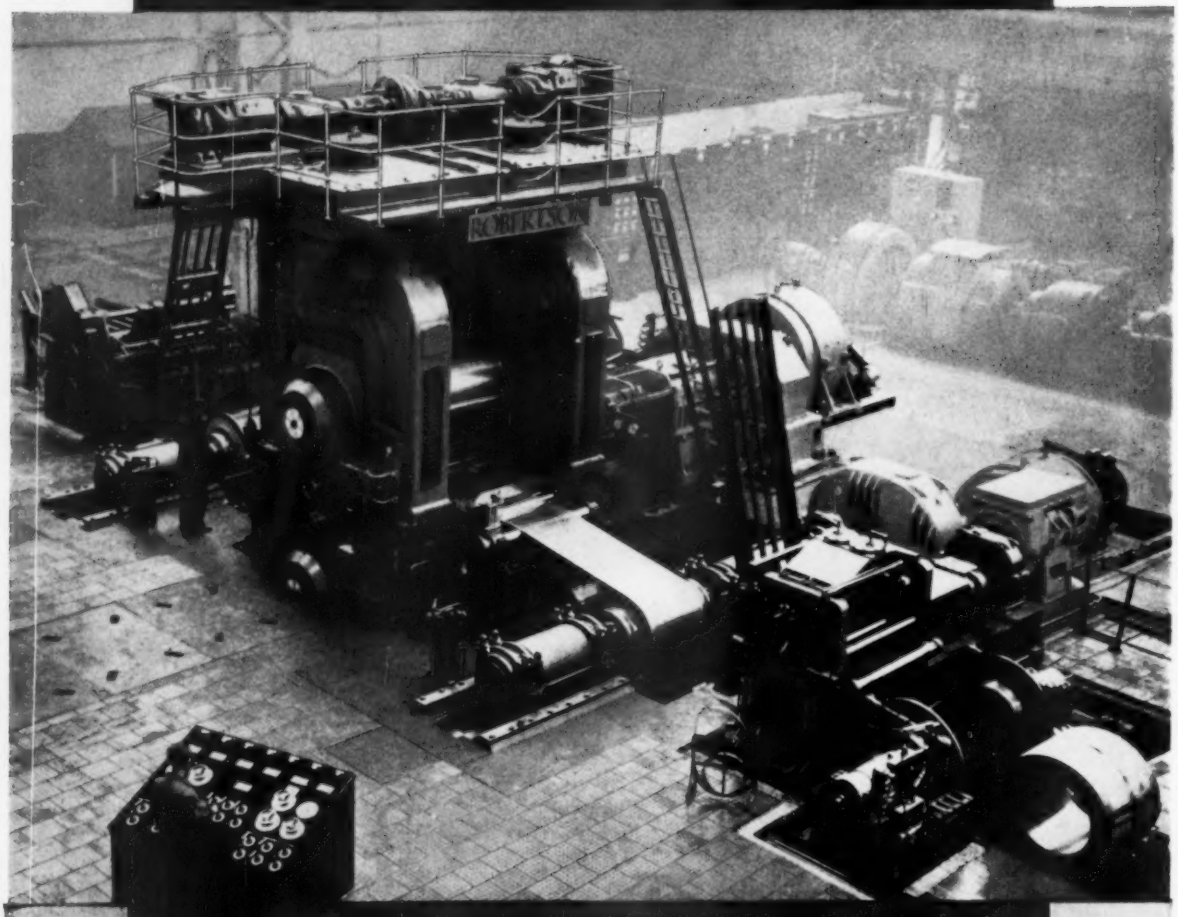

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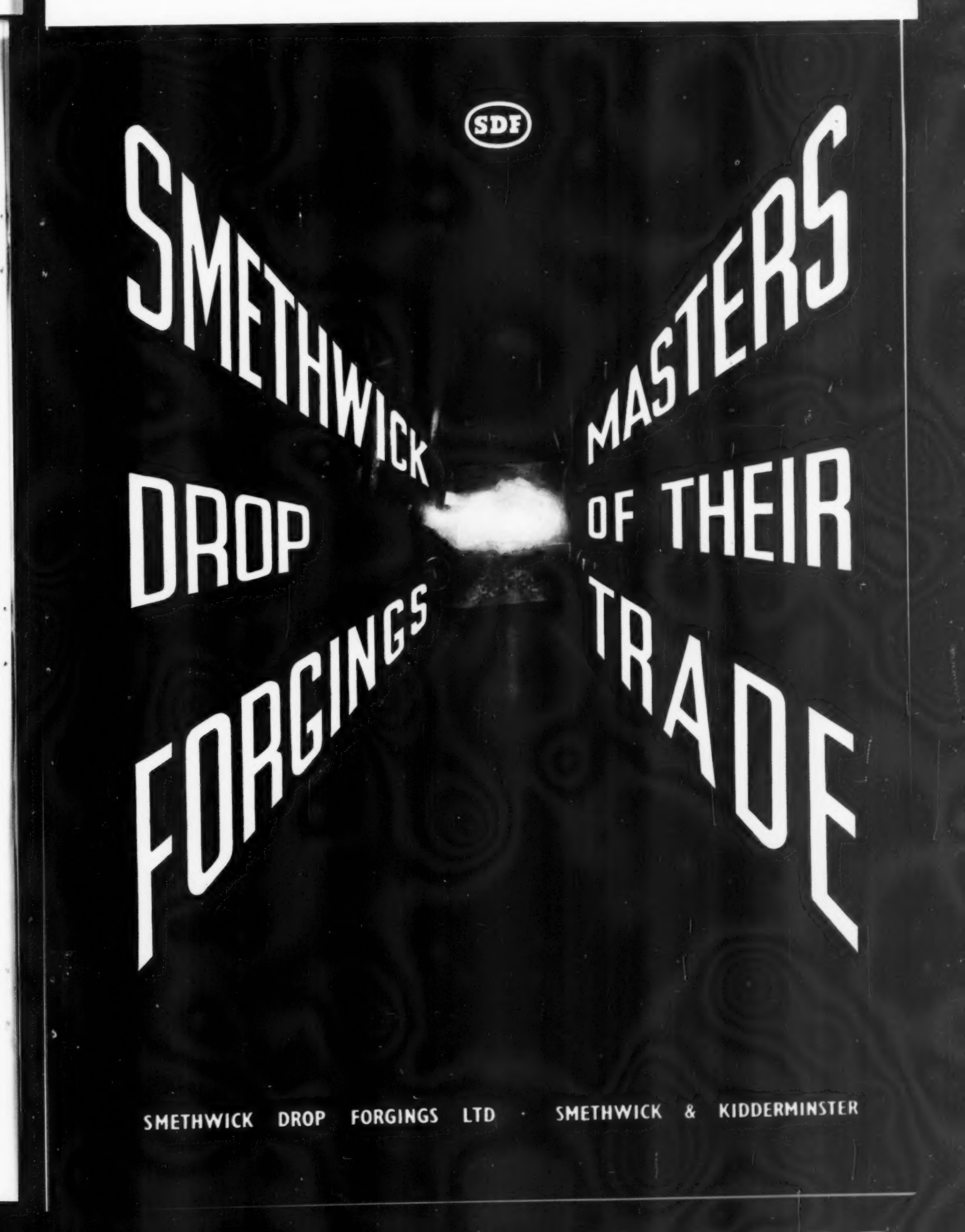
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High Temperature

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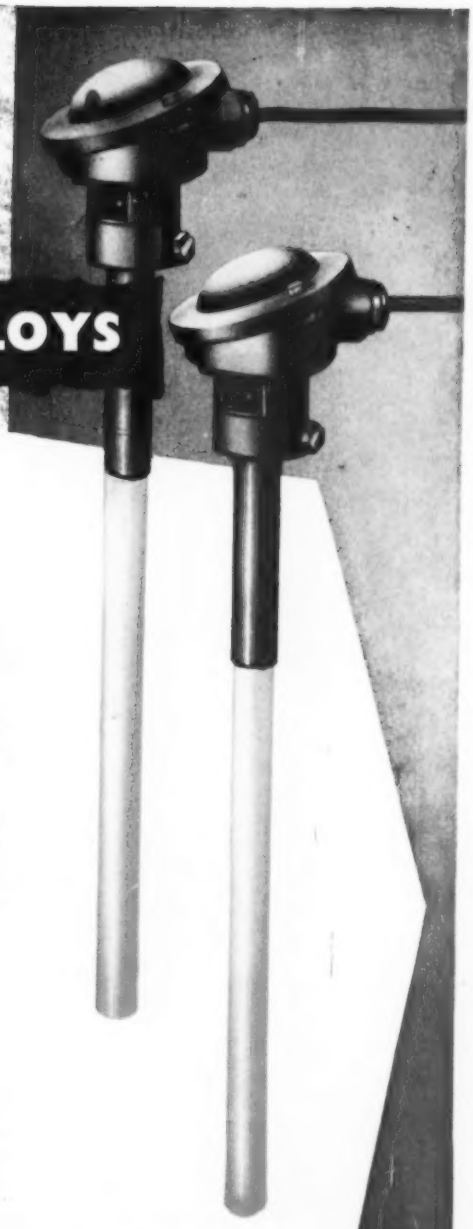

"Ni-Cr (plus) v/s Ni-Al (minus)"

Conforming to B.S. 1827:1952

The Thermo-electric properties of the Nickel-Chromium/ Nickel-Aluminium Alloys "Ni-Cr(Plus)" and "Ni-Al (Minus)", are in strict conformity with those stated in the American National Bureau of Standards Circular 561, and British Standard Institution Reference Tables for Thermocouples, B.S. 1827:1952.

For Compensating Cables and Extension Leads in Civil and Military Aircraft, "Ni-Cr(Plus)"/"Ni-Al(Minus)" Wires have Ministry of Supply (Air) type approval, for Cables manufactured to Specifications EL. 1705 and 1632.

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CONSTANTAN v PURE IRON
CONSTANTAN v H.C. COPPER

We manufacture a special quality of Thermocouple iron and are able to supply matched wires in the Iron v Constantan combination to meet customers' varied Thermal-EMF requirements. Furthermore, and of infinitely greater importance, we are able to guarantee the reproducibility of those thermo-electric properties.

When ordering Compensating Leads from your usual supplier, for greater accuracy specify: "Thermocouple Wires made by A. C. Scott & Co. Ltd., preferred".

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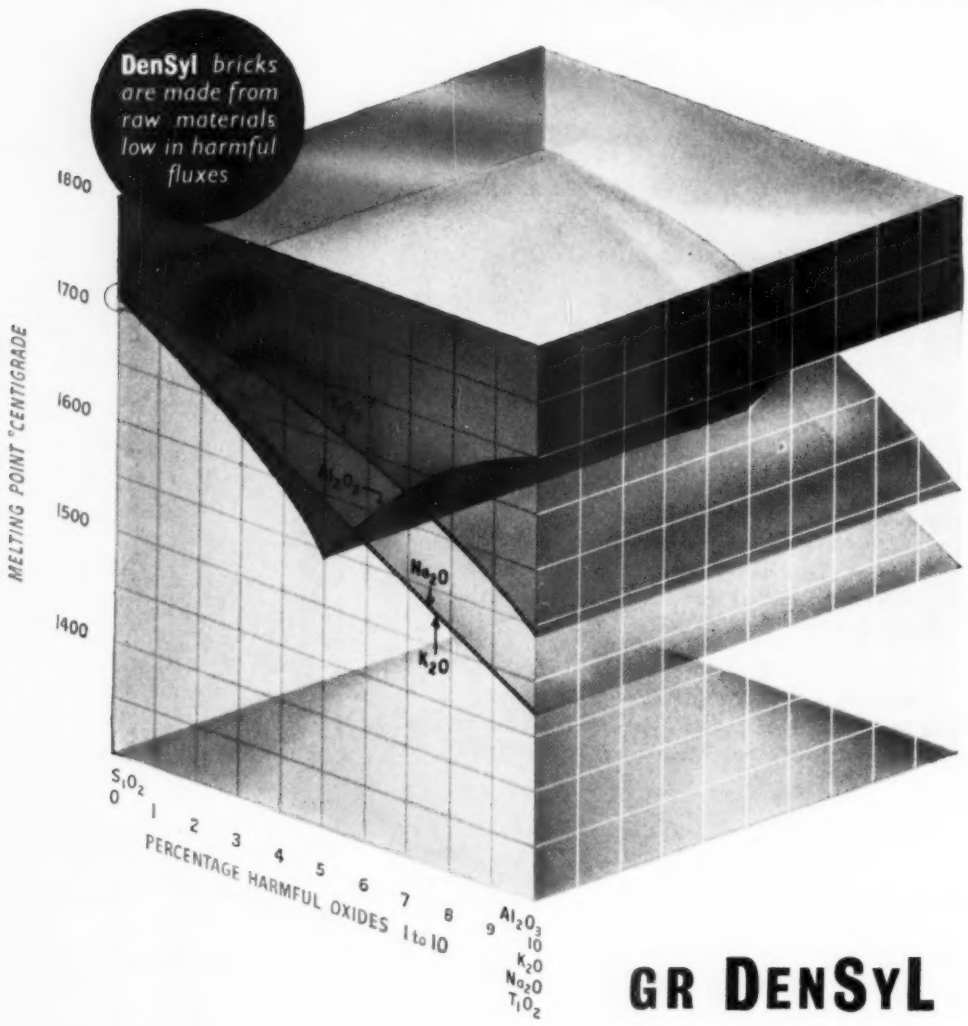

GR DENSYL

offers outstanding purity and high density

"DENSYL" BRICK sets a new standard in silica bricks intended for use at high temperatures. DENSYL is made from a new source of British (indigenous) raw material, noted for its chemical purity and uniformity. A new brickmaking process using newly developed techniques has produced a brick reaching a standard of purity and high density hitherto unattainable.

APPLICATIONS

O.H. Furnace roofs.

Glass tank roofs.

Glass tank super-structure.

Electric furnace roofs (central parts) etc.

GR Technical Services Department is available for consultation by users in the selection and application of these and other refractories.

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Nitrogen and Hydrogen for Industry

I.C.I. Ammonia provides industry with a cheap and reliable source of pure nitrogen and hydrogen. And I.C.I. gas generating plants are available to convert ammonia into a wide range of nitrogen/hydrogen gas mixtures.

Anhydrous Ammonia with a guaranteed minimum purity of 99.98% to meet more exacting requirements, is offered in bulk and in a wide range of cylinder sizes.

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A bulk delivery of 10 tons of ammonia provides over 1¾ million cu. ft. of nitrogen

Full information on request.

Imperial Chemical Industries Ltd., London, S.W.1.

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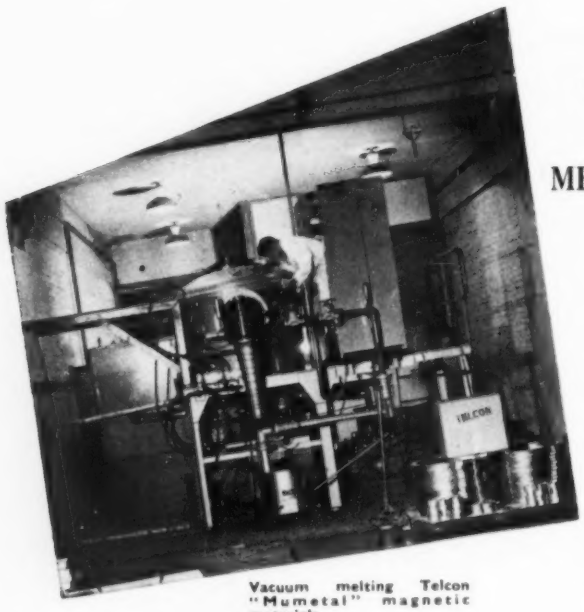

Vacuum melting Telcon "Mumetal" magnetic materials.

By courtesy of The Telegraph Construction and Maintenance Co., Ltd.

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VACUUM FURNACES

MELTING - CASTING - ANNEALING
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Whatever the material — steel — copper — magnetic alloys — reactive metals — rare metals — vacuum melting can, unlike other processes, guarantee a consistent high quality product so that little or no rejection is necessary. Suitable vacuum processes can also be employed for the production of good quality components from 100% scrap.

Powerful vacuum pumping systems, including rotary, diffusion and booster pumps, are fitted to "Speedivac" vacuum furnaces from the small ½ lb. (227 g.) to the large single and double 5 cwt. (254 kg.) production furnaces.

EDWARDS HIGH VACUUM LTD., MANOR ROYAL, CRAWLEY, SUSSEX, ENGLAND.

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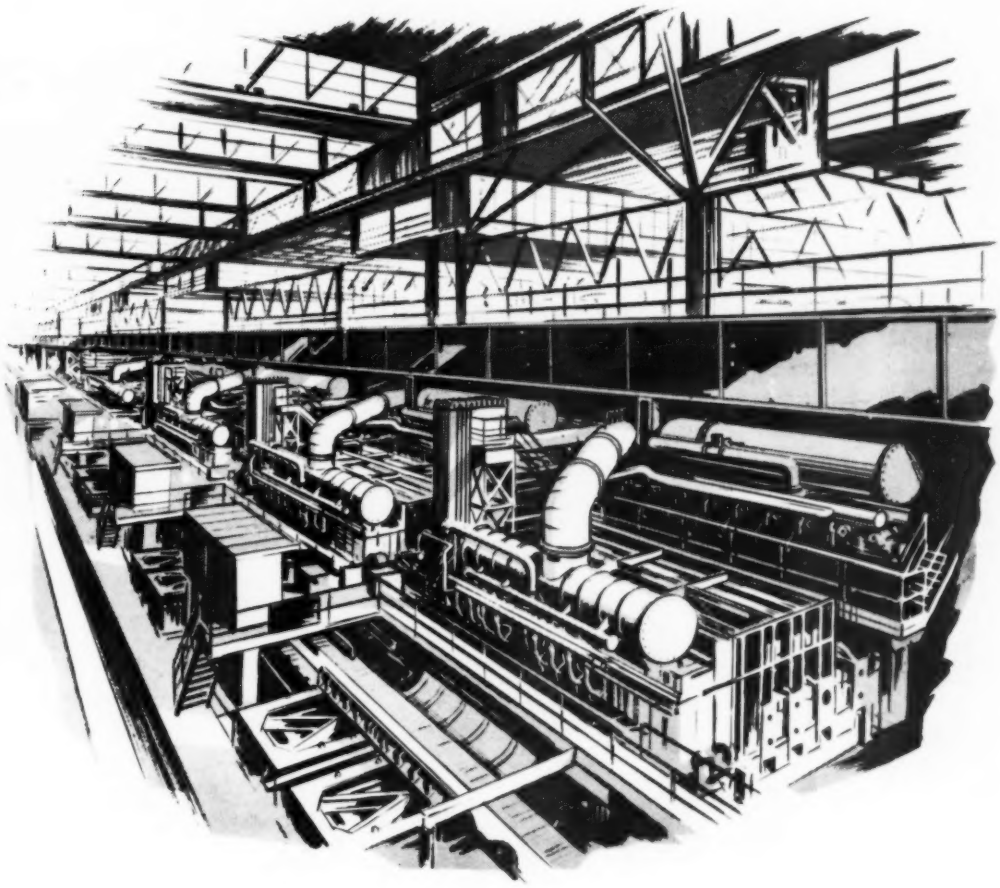

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STEEL INDUSTRY

"Rust" Zone Fired Continuous Slab Reheating Furnaces
at the Steel Company of Wales Limited

Following the installation of 3 continuous slab reheaters in 1950, each with an output of 105 tons/hour, a fourth furnace was supplied in 1954.
Stein and Atkinson are now installing a fifth furnace with an output of 135 tons/hour. This is the first 5 zone Slab Reheating Furnace to be built in Great Britain.

These repeat orders confirm the continuing confidence in the reliability of S & A furnace engineering.

S & A STEIN & ATKINSON LTD. LONDON

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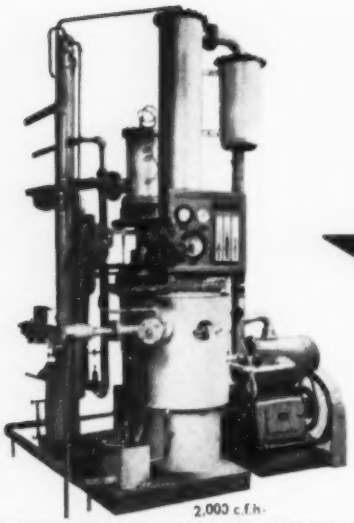
Atmosphere generators with a wide range of applications in many industries. In the metal industry for bright annealing, brazing, sintering, gas carburising, bright hardening, etc.



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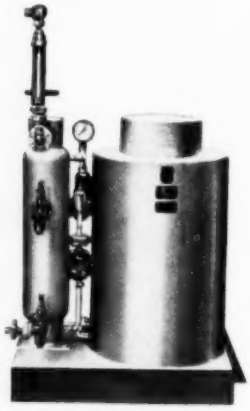
For bright treatment of stainless acid resisting and heat resisting steels, and for brazing and sintering generally.



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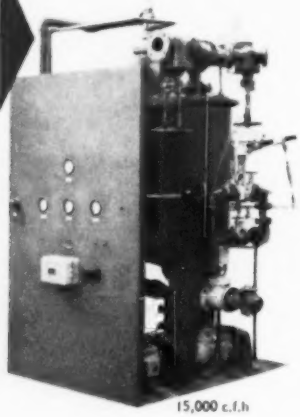
A highly efficient and compact producer of inert gas, operating on standard gaseous fuels and distillate grades of fuel oils.



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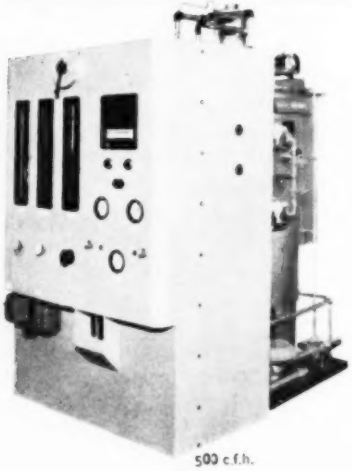
For gas carburising, dry cyanide treatment, etc. Automatic response to variations in demand while maintaining correct gas/air ratio.



500 c.f.h.

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A SUBSIDIARY COMPANY OF GIBBONS BROS. LTD.

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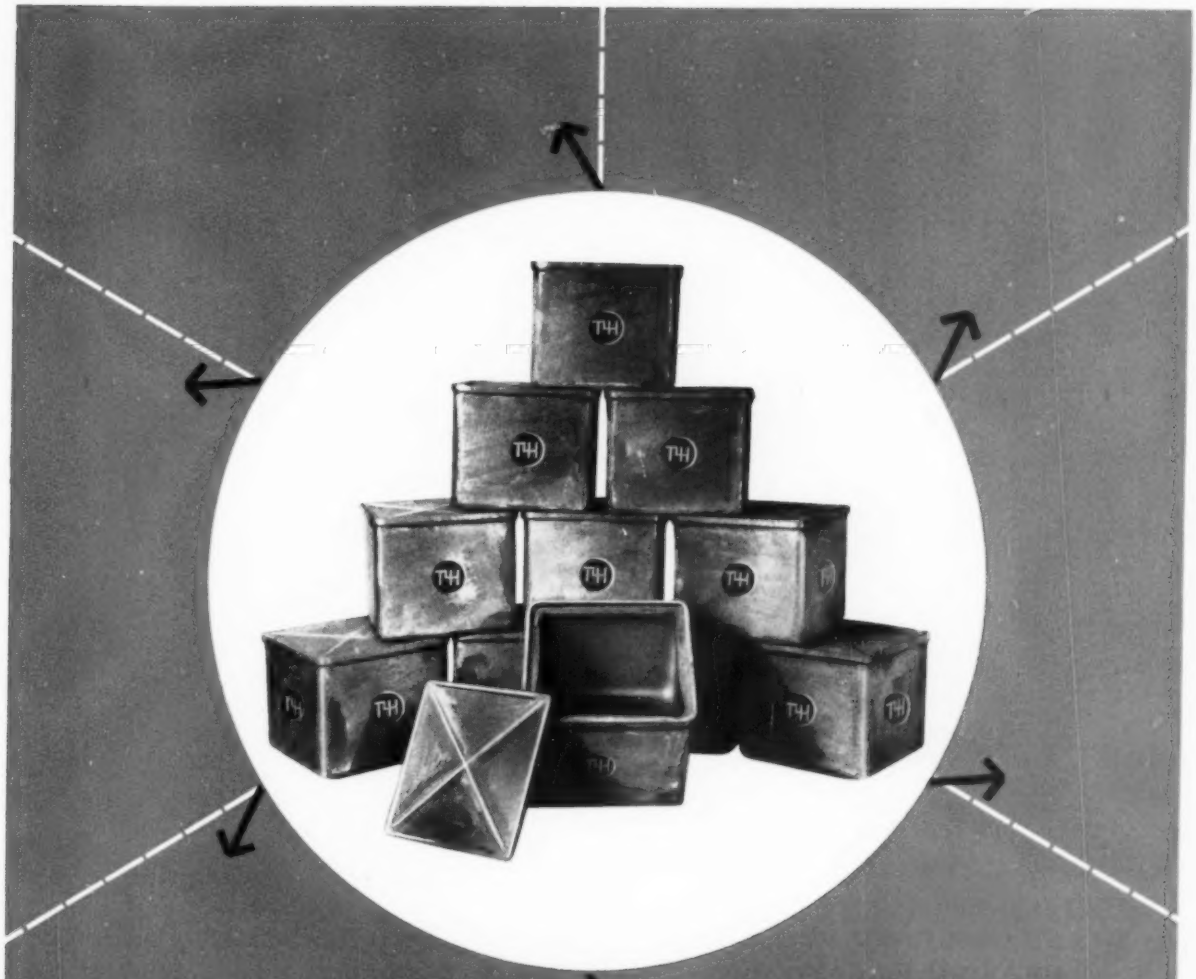

DEFEAT the HEAT

When you order or enquire for carburizing boxes from Thompson L'Hospied you are not left in peace—unless you have given us full particulars of the conditions in which they are to be used. We produce all our Heat-resisting castings from *exactly the right alloy*, so that they'll do a fine job—and do it longer—in even the fiercest heat.

That's where our long experience with the Furnace Industry benefits customers—they use us as an advice bureau—and we like it ! Our cast Nickel Chrome carburizing boxes are in constant use in heat-treatment plants throughout the country. Why not ask a representative to call on you ?

Thompson PIONEERS OF T'H HEAT RESISTING CASTINGS **L'Hospied**

A Member of the Incandescent Group

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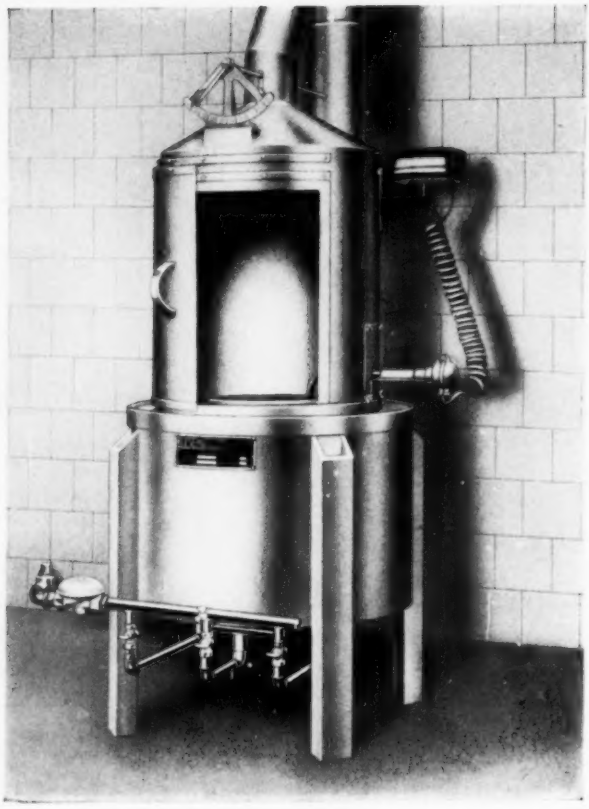
GAS BLAST COMBINED FORGE AND BRAZING HEARTH

Complete with Motor Driven Positive Air Blower, two Gas Blast Blow Pipes and one Gas Blast Burner. Suitable for Tube bending up to 1 in. diameter.

Size of Hearth, 20 in. × 20 in. × 4 in.

Gas Consumption, 200 cu. ft. per hour maximum.



NATURAL DRAUGHT GAS FIRED SALT BATH SUITABLE FOR CYANIDE OR NEUTRAL SALTS

Suitable for temperatures up to 900° C.

Obtainable in the following sizes :
8 in. dia. × 8 in. deep, gas consumption 300 cu. ft./hr.
8 in. dia. × 10 in. deep, gas consumption 350 cu. ft./hr.
10 in. dia. × 12 in. deep, gas consumption 400 cu. ft./hr.

Time to heat up—1½ hours.

Manufactured by

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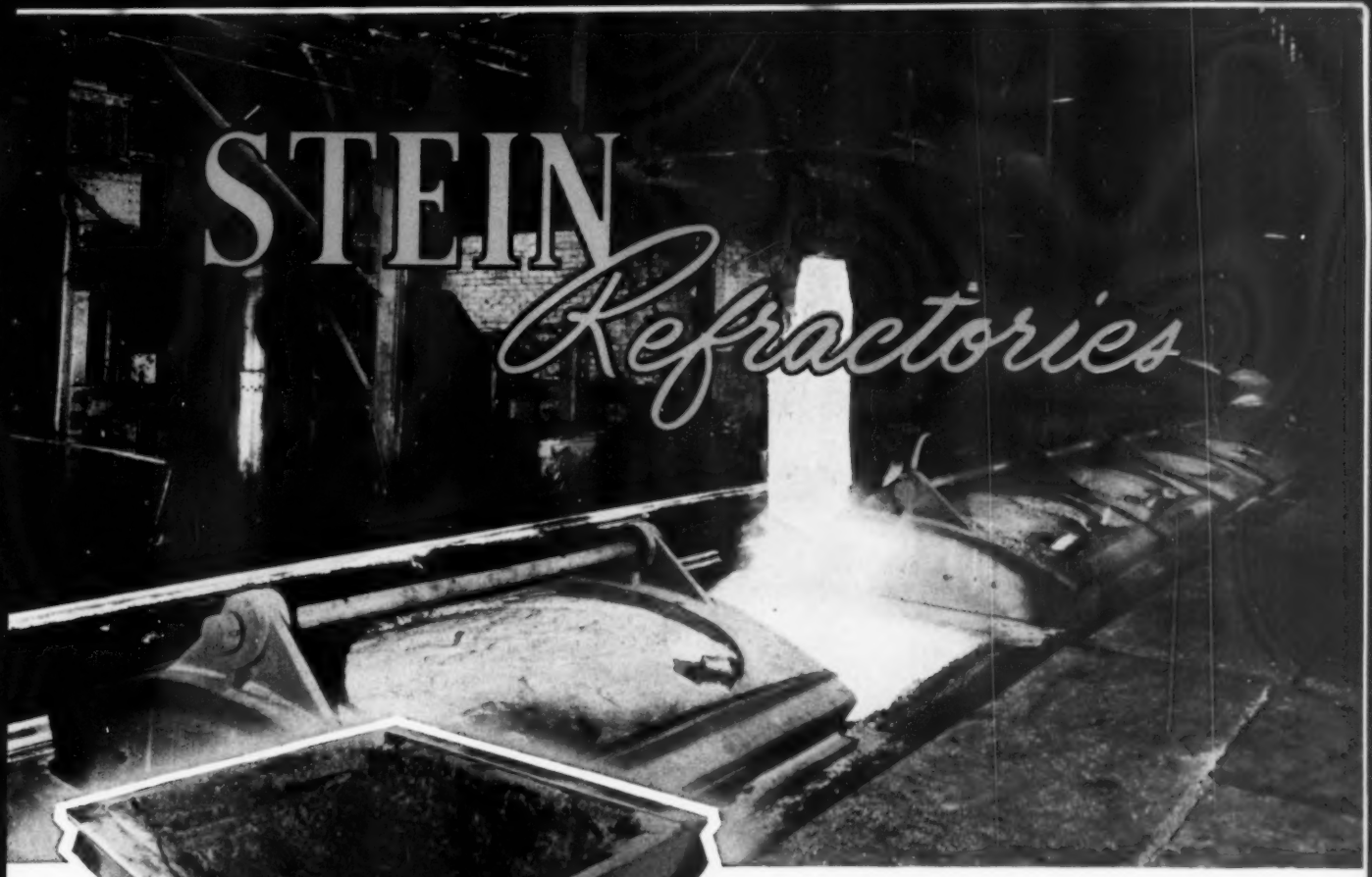
STEIN *Refractories*



REFRACTORY CONCRETES

are finding increasing applications in all manner of furnace constructions. Our illustration is of a soaking pit cover where a very useful life is regularly obtained using Stein Refractory Concrete. We can offer a range of Refractory Concretes for use up to 1800 C.—See technical data below:—

	How supplied	Refractoriness	Type of Set	Thermal Hardening Temperature	Maximum Temperature of Use	Lbs./Cub.Ft.
Stein Refractory Concrete	Dry	1420°C	Hydraulic	1200 C	1350 C	120
Stein Super Refractory Concrete No. 16	Dry	+1750 C	Hydraulic	1200 C	1600 C	160
No. 17	Dry	+1750 C	Hydraulic	1200 C	1700 C	160
No. 18	Dry	+1750°C	Hydraulic	1200°C	1800°C	160
Stein Chrome Concrete	Dry	+1750°C	Hydraulic	1200°C	1500°C	180

JOHN G. STEIN & CO. LTD. Bonnybridge, Scotland

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We can now offer the electro-metallurgical and electro-chemical
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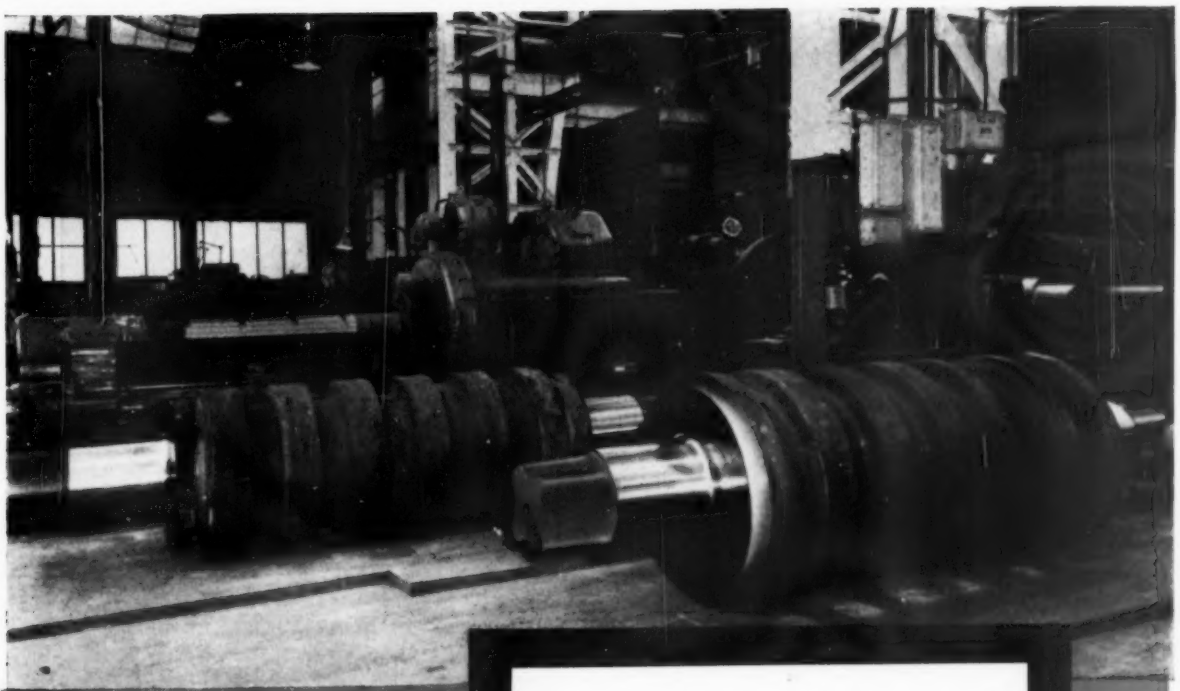

A pair of 31½" centres Alloy Grain Finishing Rolls—weight 21,280 lb. each.

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The Brightside range of rolls for hot and cold rolling is keeping pace with the exacting requirements of the steel and non-ferrous industries at home and abroad.

THE BRIGHTSIDE FOUNDRY & ENGINEERING CO. LTD.
G.P.O. BOX 118, SHEFFIELD 1.

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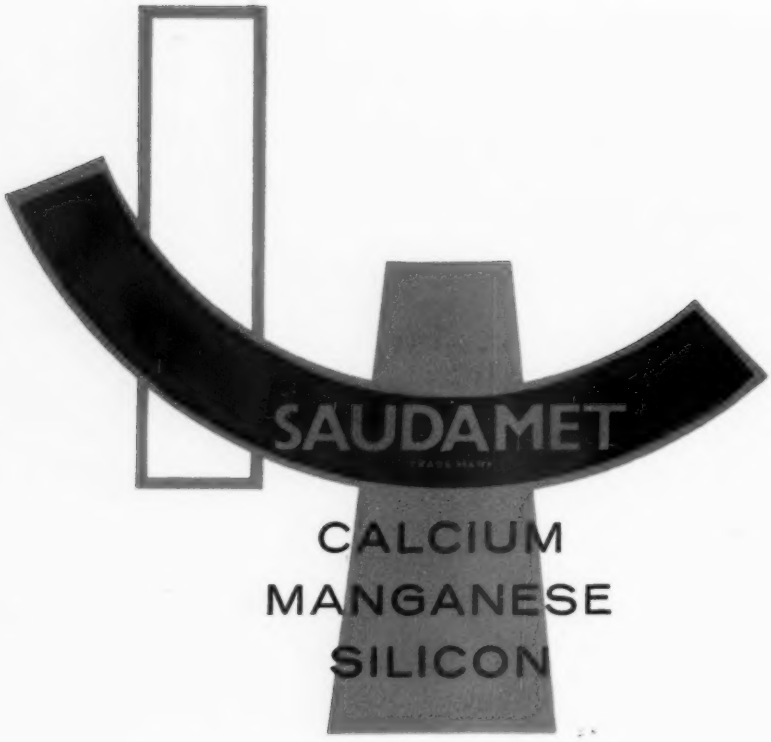

for clean steel . . . ductile steel . . . and better castability

Calcium Manganese Silicon is used as a ladle addition in the open hearth process and as both a furnace and a ladle addition in electric steel making. This combination of elements, which includes two extremely active and strong deoxidizers, produces exceptionally clean steel. It is especially helpful in the production of steel castings: in this application the combination of calcium, silicon, and manganese is effective in breaking up the harmful chain-type inclusions commonly associated with poor ductility. Castings treated with Calcium Manganese Silicon show exceptional uniformity, high ductility and freedom from internal tears.

In basic electric furnace practice, Calcium Manganese Silicon is widely used for quick deoxidation of the metal. In all electric steel, it aids in overcoming low ductility often caused by high aluminium additions. Stainless steels and certain other high-alloy steels have their castability improved by treatments with this alloy.

More information about this excellent alloy (Ca 16-20%, *Mn* 14-18%, *Si* 55-60%) *can be obtained from Union Carbide Limited, Alloys Division,* 103 *Mount Street, London, W.*1. (*Telephone HYDe Park* 5361).

The terms UNION CARBIDE and SAUDAMET are trade marks.

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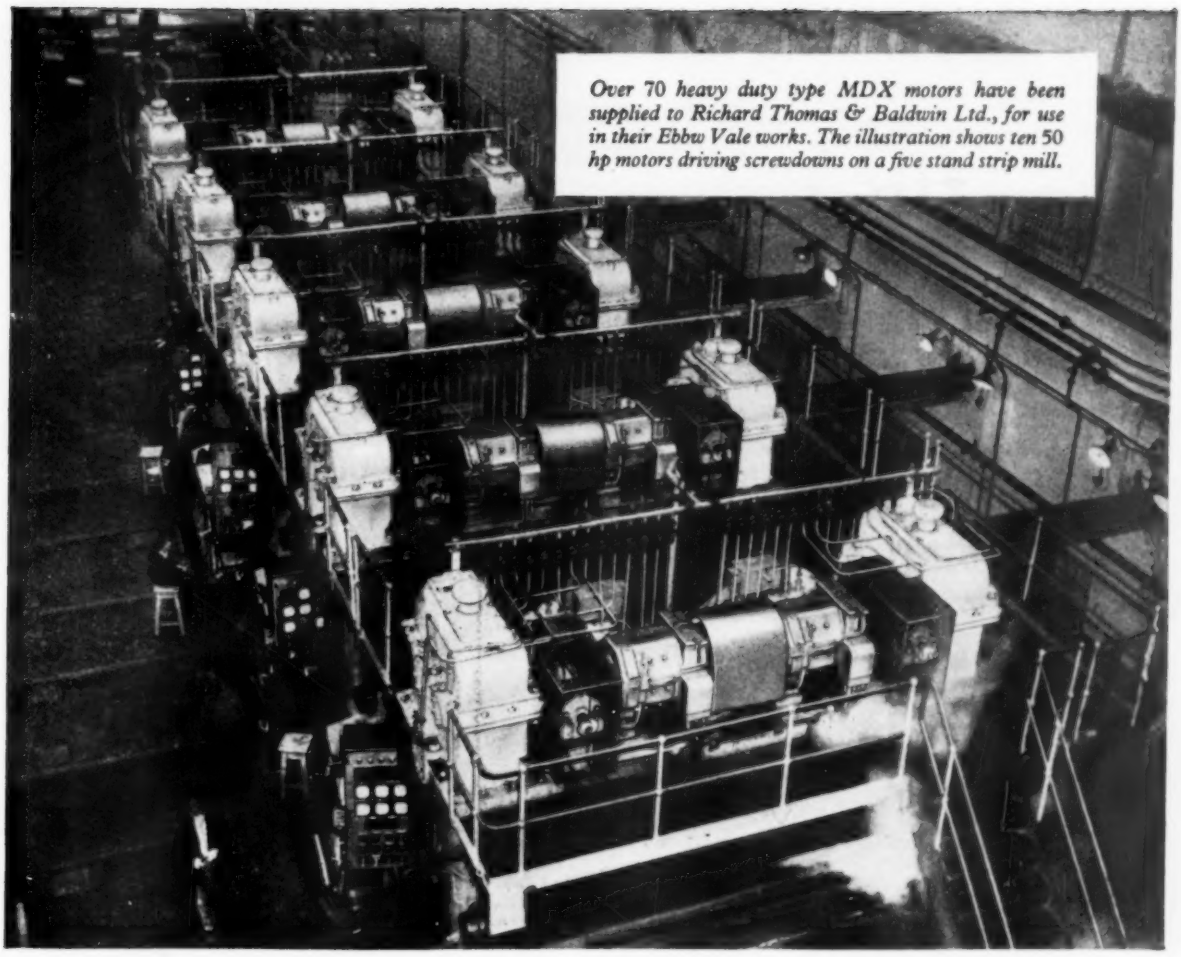
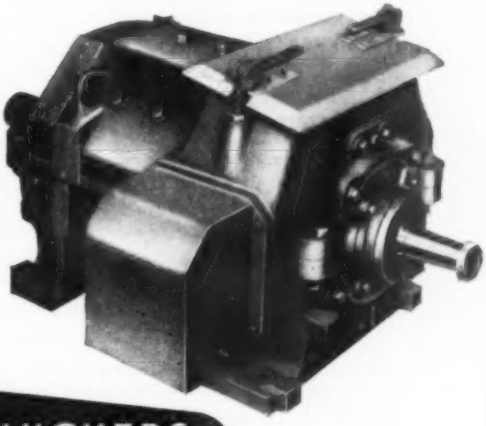


Over 70 heavy duty type MDX motors have been supplied to Richard Thomas & Baldwin Ltd., for use in their Ebbw Vale works. The illustration shows ten 50 hp motors driving screwdowns on a five stand strip mill.

All motors here are type MDX

Metrovick type MDX motors have been specially designed to operate under the arduous conditions of iron and steel works. Their strength and reliability, and the exceptionally low inertia of the rotating parts make these machines ideal for driving a wide range of steelworks equipment. The use of mica and glass insulation suitable for high temperature operation enables the motor to withstand heavy overloads.
Available totally enclosed, up to 200 hp, or self-ventilated, up to 250 hp.



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ELECTRICAL CO LTD TRAFFORD PARK MANCHESTER 17

An A.E.I. Company

Metrovick Motors for Trouble Free Service

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PYROSCALE EDGEWISE INDICATORS AND PYROCOUPLES

Pyroscale Edgewise Indicators are designed for use on Furnaces, Salt and Metal Baths, Ovens and Infra-red tunnels, Diesel Engines, Boilers and Power Plant, Diecasting Machines, Injection moulding machines and other applications where accurate temperature measurement is vital.

They are available for wall and flush panel mounting in calibrated scale lengths of 4", 6" and 8" and have a knife edge pointer with anti-parallax mirror, which ensures accurate readings. They combine robustness and accuracy to give a high quality instrument at reasonable cost.

- PYROSCALE EDGEWISE INDICATORS
- PYROSCALE PORTABLE INDICATORS
- PYROSWITCH MULTI-POINT PYROMETERS
- PYROCOUPLES
- FOUNDRY PYROMETERS
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- MECHANICAL PYROSTAT CONTROLLERS
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Cut out this advertisement and indicate which of the above leaflets you would like to receive.

A variety of Pyrocouples are manufactured and it is of primary importance that the most suitable arrangement is selected to combine adequate response and reasonable life, in accordance with the operating conditions of temperature and atmosphere.

Automatic Temperature Control Equipment, mechanical or electronic type, is also available.

THE INDUSTRIAL PYROMETER CO. LTD

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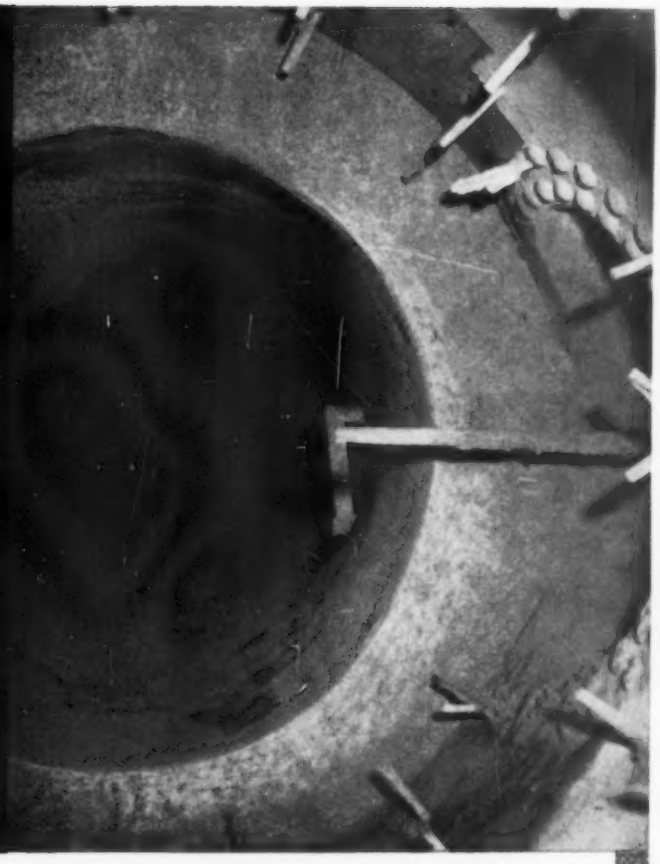
Tri-Mor Plastics and Castables make installation Easier Quicker and Cheaper



Bustle main of Queen Victoria Blast Furnace showing 'gunned' lining in Tri-Mor Dense 'Guncrete'. (Inside diameter of shell 5 feet. Thickness of 'Guncrete' lining 9 inches).
Photograph by courtesy of the Appleby-Frodingham Steel Co. (Branch of the United Steel Companies Ltd.).

TRI-MOR GRADES

TRI-MOR *Standard Castable*

A medium texture refractory having negligible shrinkage up to 1,350 C. Suitable for casting special shapes or for monolithic structures. Limiting service temperature 1,350 C.

TRI-MOR *High Strength Castable*

A similar refractory to Tri-Mor Standard Castable, but specially developed to have very high mechanical strength over the lower temperature range. Maximum service temperature 1,250 C.

TRI-MOR *High Temperature Castable*

Suitable for face temperatures up to 1,600°C; has an extremely high resistance to thermal shock; used for cast in situ monolithic structures and for pre-cast refractory shapes; can be applied with a cement gun.

TRI-MOR *High Temperature Mouldable*

A plastic refractory for use up to 1,650 C: low shrinkage and a high resistance to spalling. Supplied mixed to the correct consistency for installation.

TRI-MOR *Dense "Guncrete"*

A hydraulic setting refractory with a maximum service temperature of 1,300°C. It has a high resistance to abrasion. Designed for application by cement gun, but can be trowelled.

TRI-MOR *Insulating Castable*

An insulating castable for maximum service temperatures of 1,200°C; low thermal conductivity is its main feature.

TRI-MOR *Insulating "Guncrete"*

Similar to Tri-Mor Insulating Castable but for application by cement gun.

Full details of each grade are available on request.

MORGAN Refractories Ltd

For further information write to: MORGAN REFRACTORIES LTD
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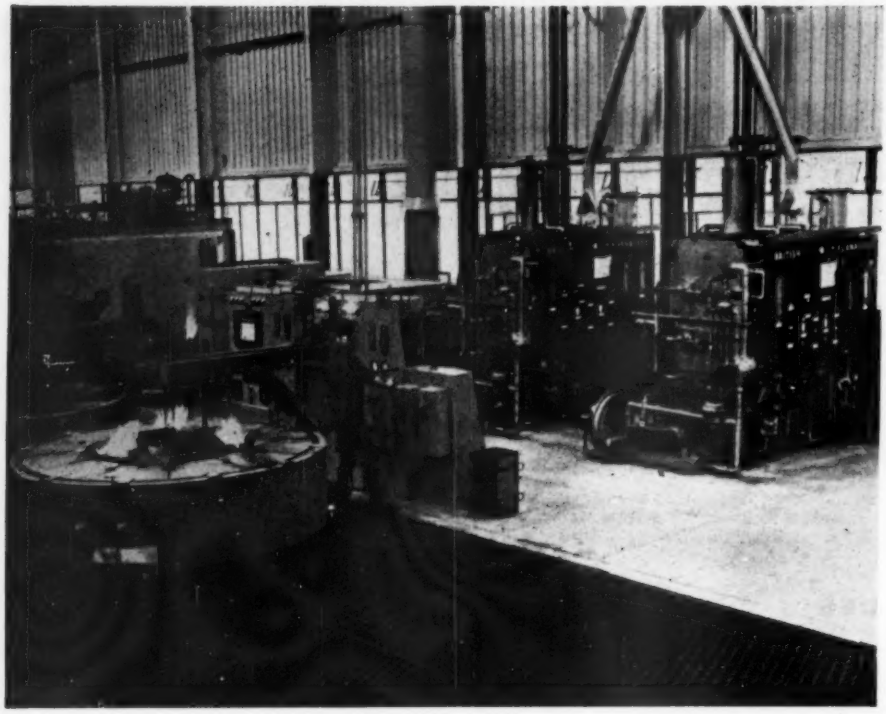

GAS CARBURISING FURNACES AT CATERPILLAR TRACTOR CO. LTD.

Two radiant tube gas fired pit type gas carburising furnaces with containers 30 in. dia. by 48 in. deep for gross loads up to 3,350 lb.

These and other furnaces in the factory are supplied with an endothermic gas from the two generators in the background and a further generator is being installed.

Caterpillar, manufacturers of the 225 h.p. D8 Series "H" Crawler Tractor (above) have after 25 years' experience, again chosen gas carburising furnaces for their new Glasgow factory.

BRITISH FURNACES LIMITED—CHESTERFIELD

ASSOCIATED WITH SURFACE COMBUSTION CORPORATION · TOLEDO — U.S.A.

Picture of a man . . .

. . . with all the answers on insulating bricks

He is finding that the use of insulating bricks for more effective heat insulation has been a subject well worth looking into. Reading further he'll see that Newalls make a range of insulation bricks under the trade names "Nonpareil" and "Newparex" which are designed to cover heat insulation requirements up to 2012°F (1100°C). But why not read the catalogue yourself? Like the man in the advertisement, you'll find factual answers to all your queries.

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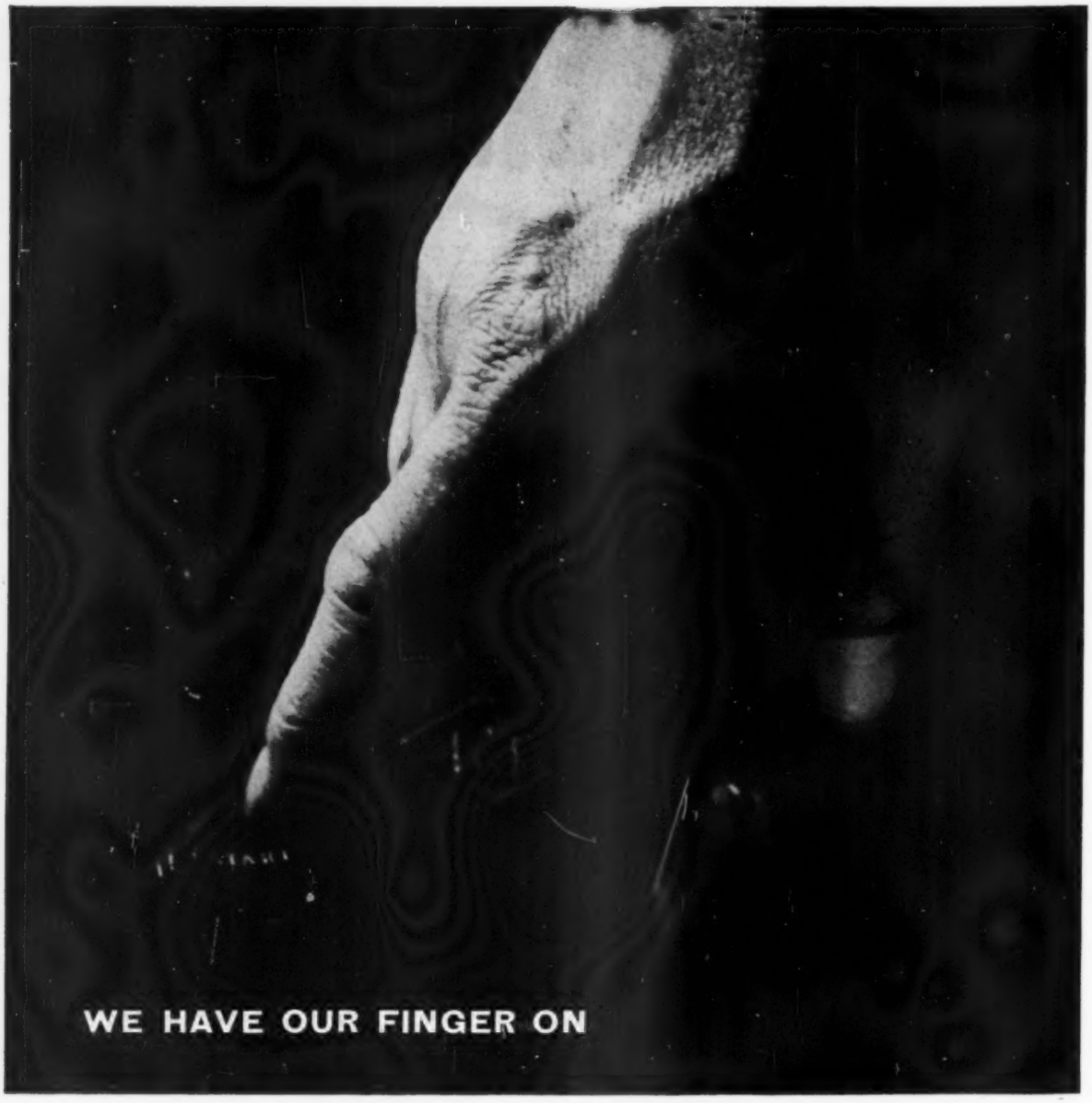

HIGHER STEEL PRODUCTION

Iron was first made at Brymbo in 1798; steel in 1885. This year sees a further landmark—the dismantling of the open hearth steel furnaces. These were once the first of their kind in the United Kingdom. Now they give way to all-electric plant. With the completion of this part of their current development programme, Brymbo Steel Works Ltd., become one of the largest producers of electrically melted steels in the country. Production—and productivity—have never been higher.

THE BRYMBO RANGE *of slabs and billets covers all types of low alloy and special carbon steels, including silico-manganese.*

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(One of the GKN Group of Companies)

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2. Bearing life consistently up to 600% longer for high temperature, high speed applications.
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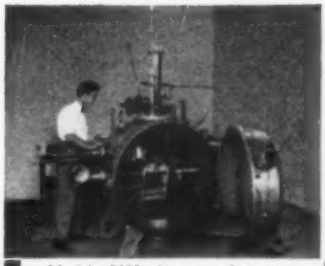
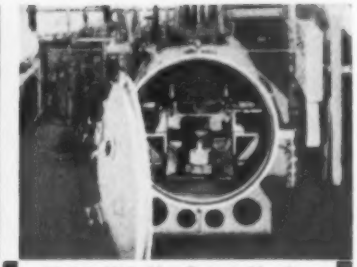


Model 2555 Vacuum Induction Furnace with melting capacity of 50 pounds of steel. Other standard furnaces have capacities of 12 to 3,000 pounds.



Model 2705 Non-Consumable Arc Skull Furnace with a capacity of 50 pounds of titanium. Other standard vacuum arc furnaces have capacities of 8 to 10,000 pounds of titanium.

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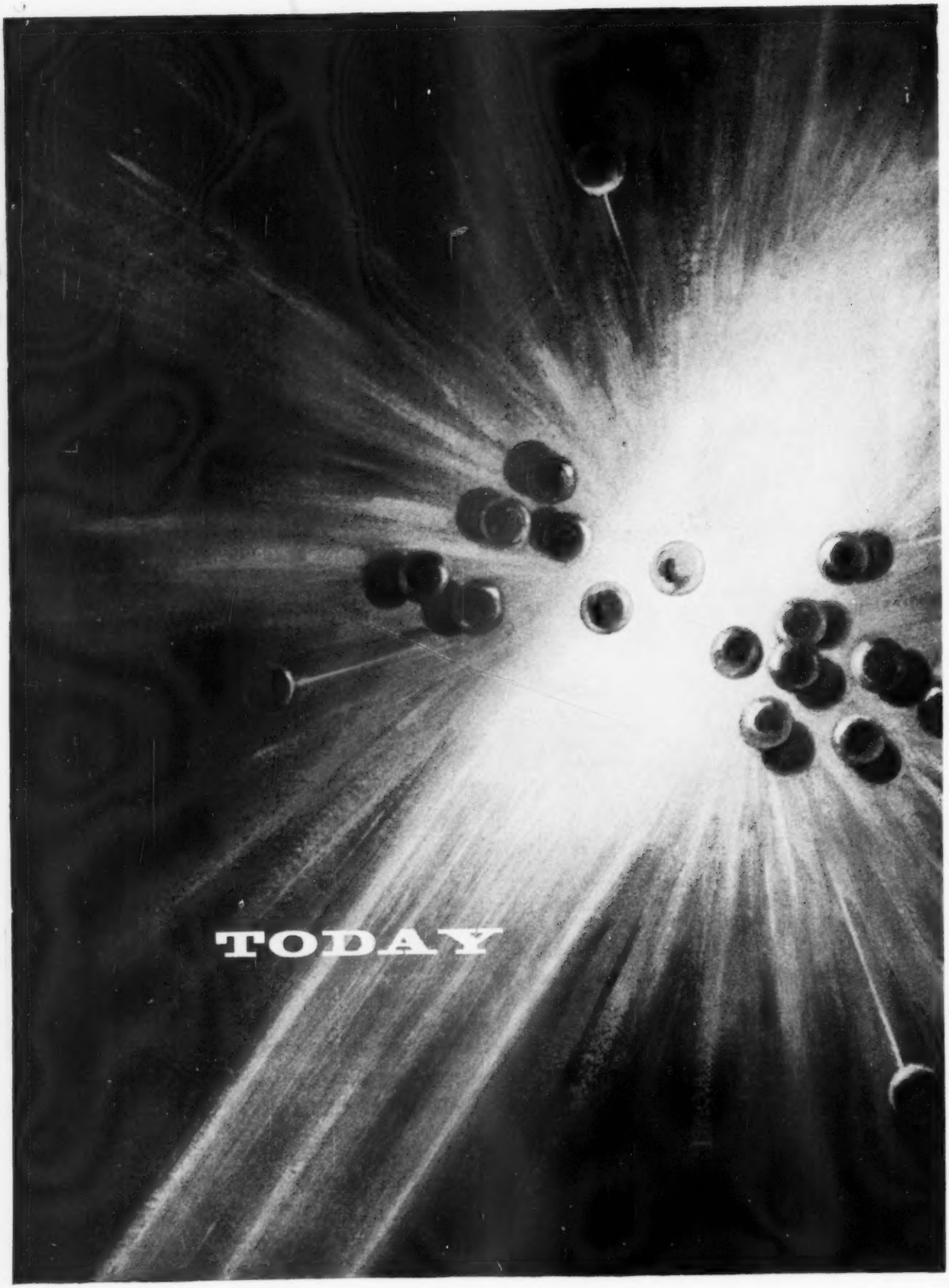
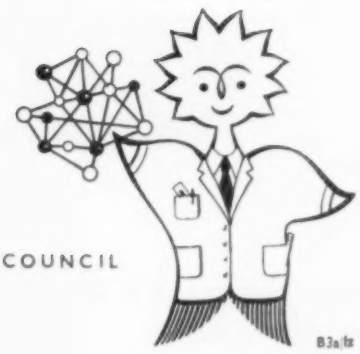

TODAY

TOMORROW

Gas Industry research today aims at faster heating through high intensity gas burners so that gas will be even more a major heat source for tomorrow's manufacturing processes . . . AND TODAY—every industry and 12 million homes use GAS.



ISSUED BY THE GAS COUNCIL

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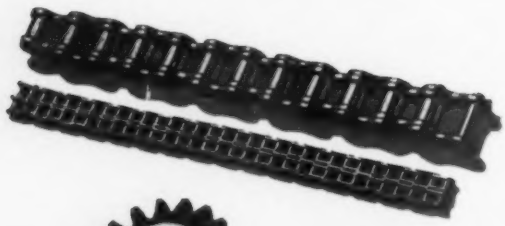
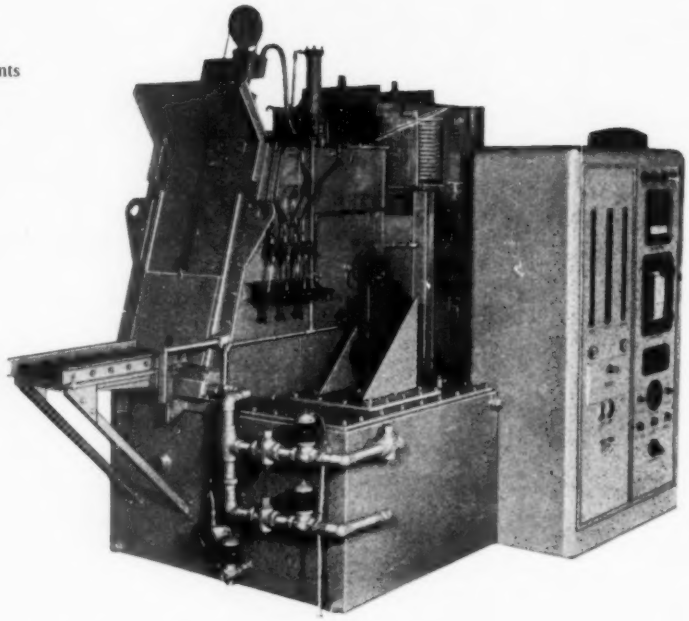


Roller chain parts carbonitrided in Efco-Lindberg Carbonitrider by Morse Chain division of Borg-Warner Ltd

Ford motor gear parts carbonitrided in Efco-Lindberg Carbonitrider

Wear resistant parts like these *are Carbonitrided in EFCO Furnaces*

Cash register, roller chain, and motor car manufacturers use Efco furnaces for carbonitriding components that must withstand impact and wear. A typical Efco-Lindberg carbonitrider is the standard CT–122410–A3 furnace illustrated. This is heated by the new Corrtherm electrical elements located in the side walls, the current being supplied through aluminium busbars from a special transformer situated on the top of the furnace. The charge dimensions are 12 in. wide × 10 in. high × 24 in. long, and the output for straight hardening is about 100 lb. per hour. Standard sizes are available up to 24 in. wide × 18 in. high × 48 in. long.



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The Efco-Lindberg Corrtherm element is a sheet of corrugated nickel chromium which practically covers the walls of the furnace, and operates on an extremely low voltage. It eliminates current leakage due to carbon deposition, has very long life, gives uniform heat distribution, and eliminates risk of harm to operators through accidental contact.

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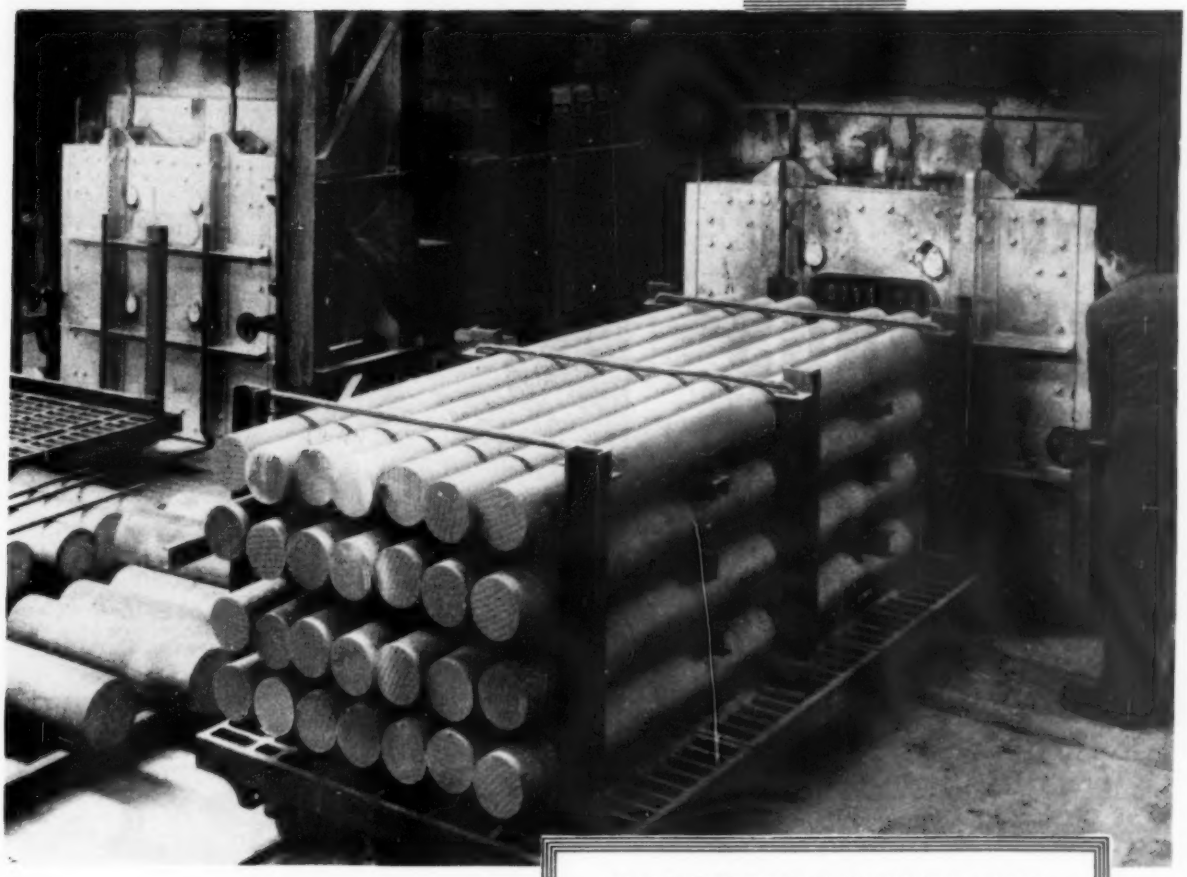

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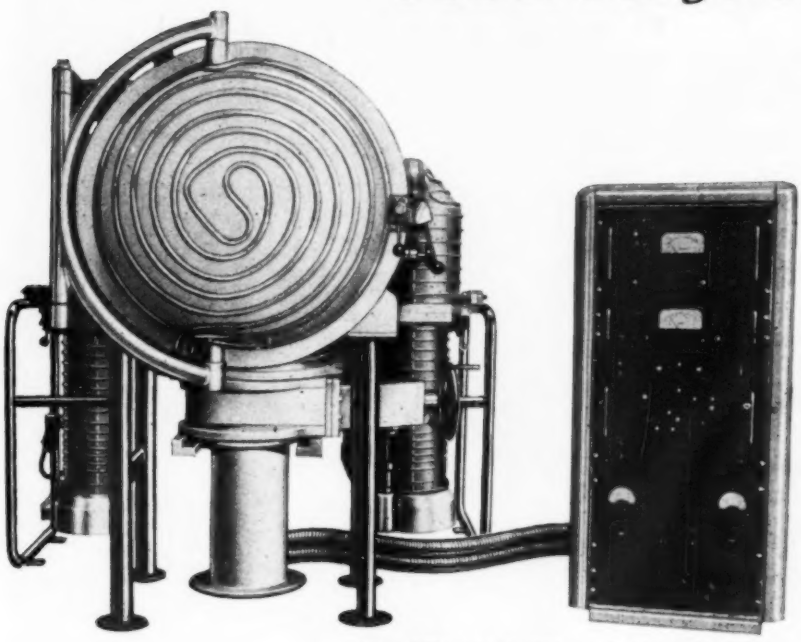
TYPE FH 30 S



The VIA-VAC FH 30 S High Vacuum Furnace is specially designed to melt, cast or sinter metals at low pressures, using resistance or high-frequency induction heating.

The new range of VIA-VAC furnaces satisfy two main demands.

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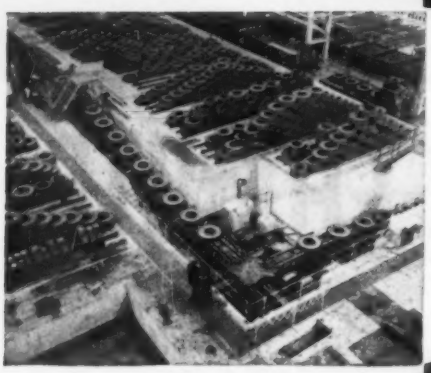
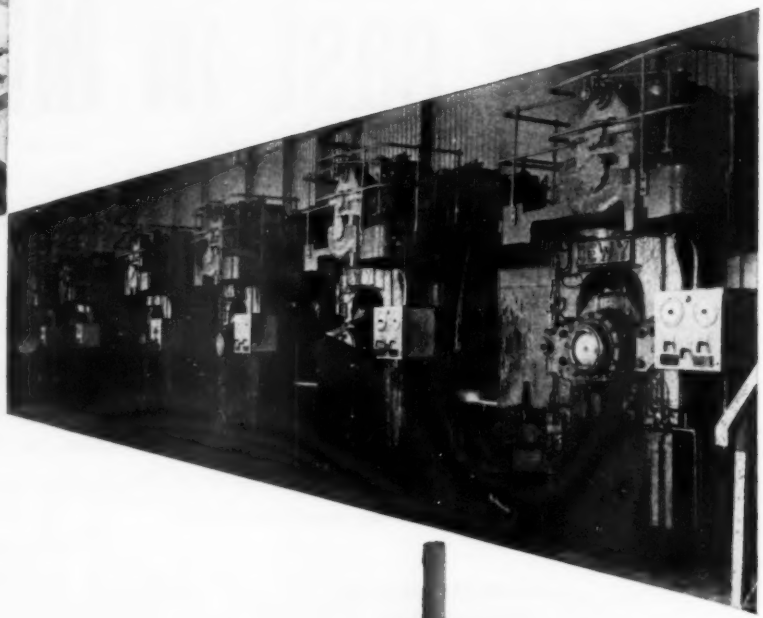
HOT ROLLED STEEL STRIP





The new Brinsworth mill hot rolls steel strip

—in widths from 6 to 18 inches

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SP 218

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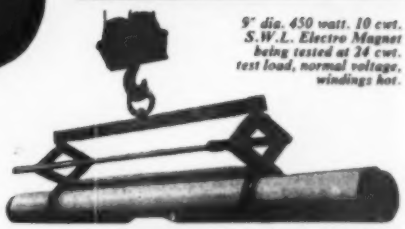
Vertical cylindrical specified diameter lifting device.

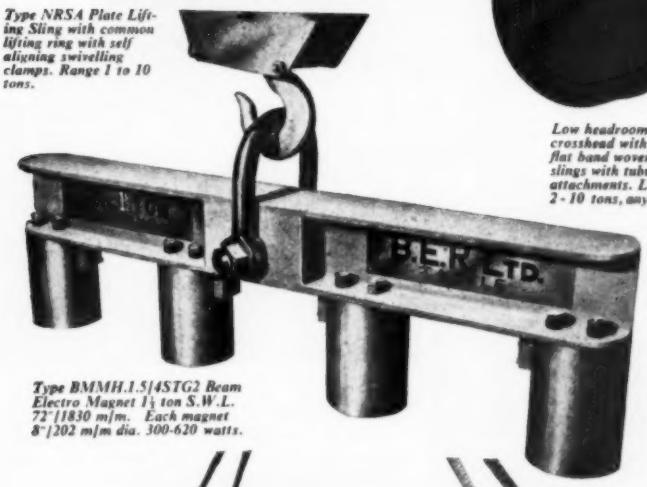
Horizontal cylindrical specified diameter lifting device, also supplied with special clamp faces for handling ground diameters.

Type NRSA Plate Lifting Sling with common lifting ring with self aligning swivelling clamps. Range 1 to 10 tons.

Low headroom all steel crosshead with pair of flat band woven wire slings with tubular end attachments. Load range 2 - 10 tons, any diameter.



9" dia. 450 watt. 10 cwt. S.W.L. Electro Magnet being tested at 24 cwt. test load, normal voltage, windings hot.



Type BMMH.1.5/4STG2 Beam Electro Magnet 1½ ton S.W.L. 72"/1830 m/m. Each magnet 8"/202 m/m dia. 300-620 watts.

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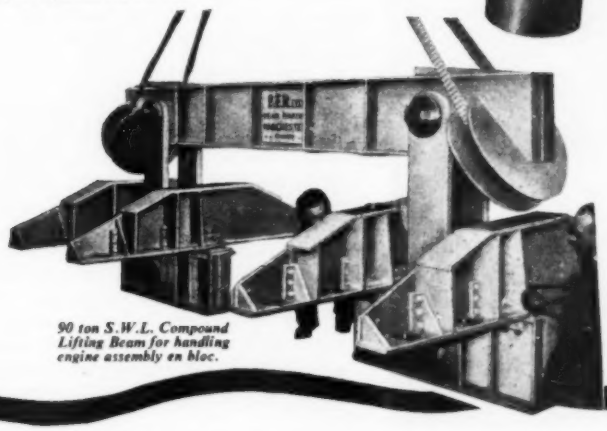

90 ton S.W.L. Compound Lifting Beam for handling engine assembly en bloc.

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An example is the electrically heated Pusher Furnace supplied
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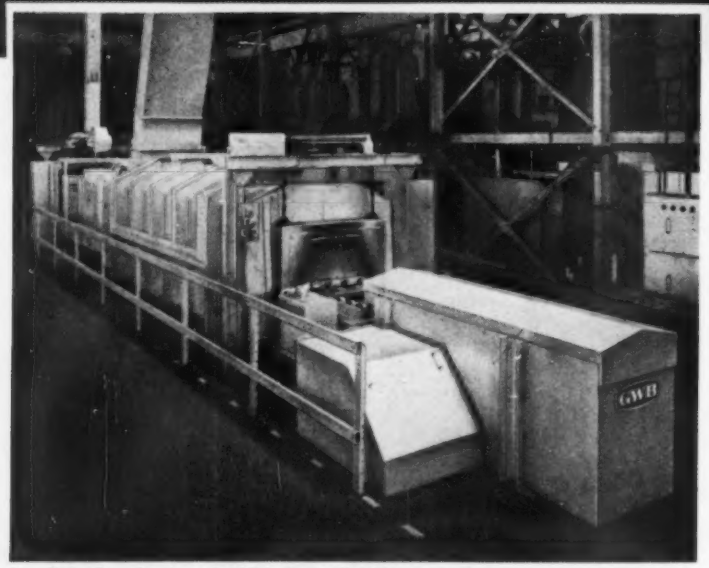

Overall view from charging end of 145 kw Pusher Type Normalising Furnace at Albion Motors Limited

APPLICATION

Various forgings such as main shafts, countershafts, pinion shafts and gear blanks are normalised by heating up to 900° C. and slow cooled down to 400/500° C.

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The only labour required is for placing the components into the charge trays at the entrance end of the furnace. By pressing a button, the following cycle automatically takes place. (1) The entrance door rises. (2) The pusher ram propels the loaded tray into the furnace. (3) The ram returns. (4) Entrance door lowers. (5) Exit door rises. (6) Hydraulically operated go-getter pulls last tray from exit end of furnace on to a cross conveyor. The cross conveyor moves the normalised parts to the top of an inclined roller track where the tray is unloaded by a tipper, and then returns empty to the entrance end of the furnace.

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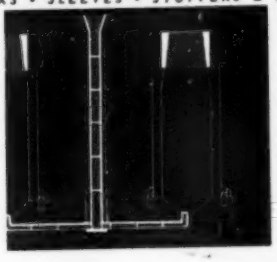

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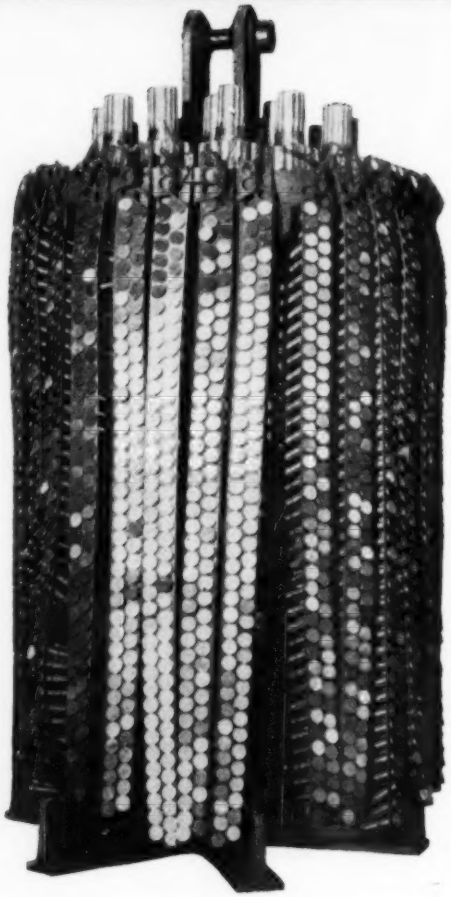

Compactness of furnace layout is matched by the amazing density of loading in these INCANDESCENT gas carburizing furnaces. Such performance is made possible by two special INCANDESCENT features

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May 21st-30th 1959
see our exhibit
Stand No. 72

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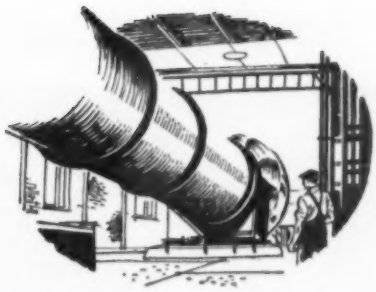
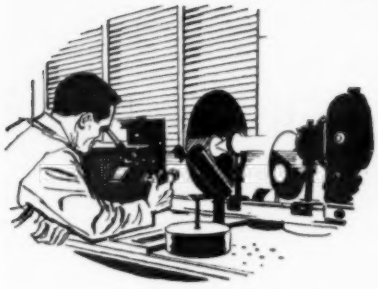


One million pounds for a pound



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INCORPORATING THE METALLURGICAL ENGINEER

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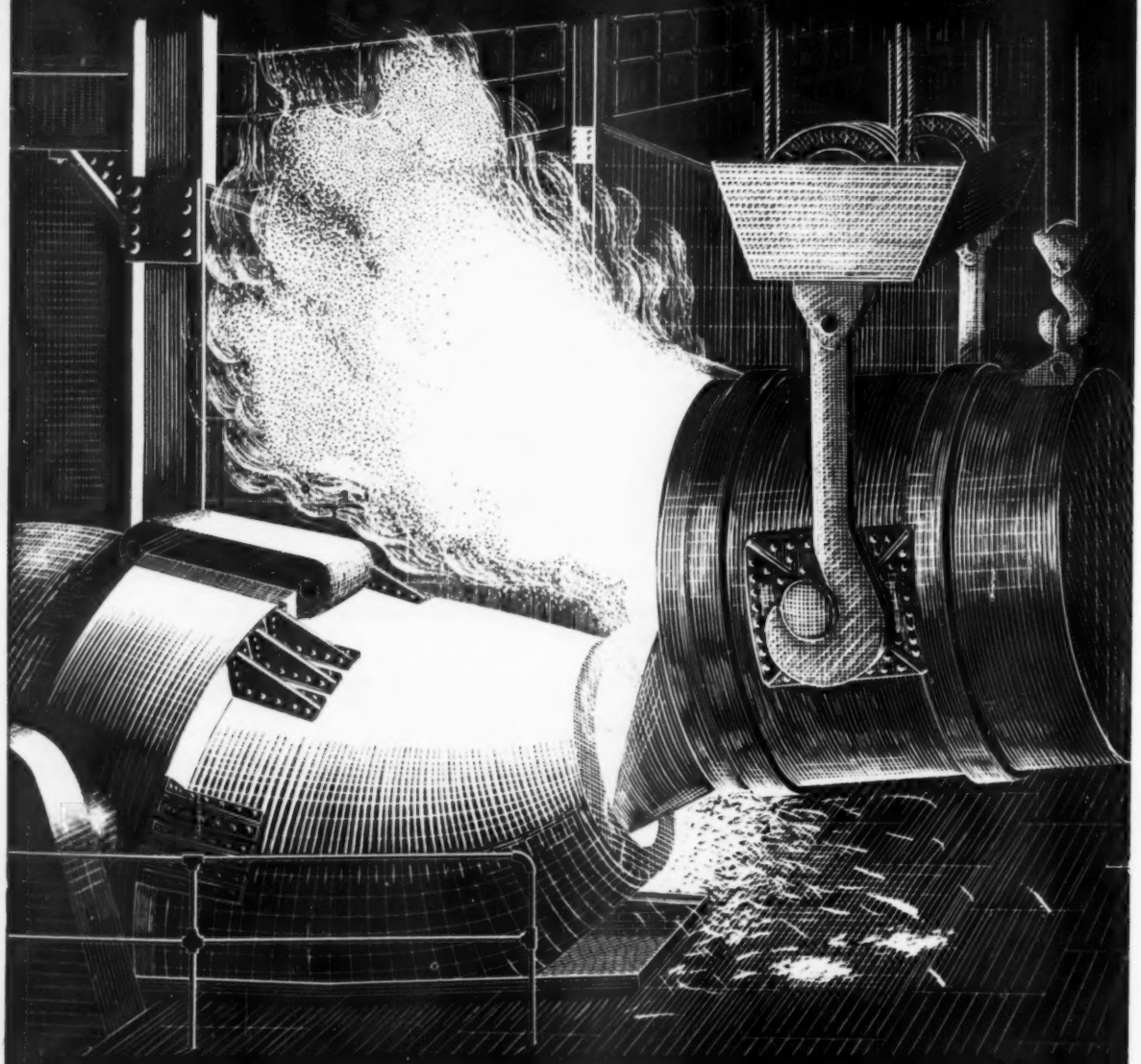

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Electric Steel Melting

SOME fifty years have passed since the electric arc furnace first made its appearance as a melting unit in the steel industry. The earliest furnaces had capacities up to 2 tons, and were rectangular or polygonal in plan view, with two or three hand-operated carbon electrodes projecting through the roof. Considerable progress has been made since those days, and at the present time units of some 150–200 tons capacity are in operation, and more than 18 million tons of steel are produced each year in the various types of electric melting unit. The figure for this country alone is well over a million tons, which represents a tenfold increase on the 1935 figure.

The use of high frequency electric current for the commercial melting of steel dates back to 1925, since when this type of unit has found widespread application for melting both ferrous and non-ferrous metals. It differs from the arc furnace in an important detail, in that it is essentially a melting and not a steelmaking unit. Roughly speaking, one gets out of a high frequency induction furnace what one puts in, which is no bad thing if one is melting scrap containing costly elements. Another valuable feature of this type of furnace is the continuous stirring action, due to the eddy currents.

Although crucible sizes range from a few pounds to several tons, the most popular sizes lie between 10 cwt. and 30 cwt. Melting costs are of the same order as with electric arc furnace melting, since although amortisation costs are high, due to the large capital outlay involved, this is largely offset by the absence of electrode costs. Power costs per ton are little higher than with much larger arc furnaces, and the lining costs are about the same. Improved reliability of the electrical equipment in recent years has reduced maintenance charges to a low figure.

The skill required of the operators is probably less in the high frequency furnace than in other methods of steel melting, which is helpful in the attainment of a consistently high quality product. The induction furnace is never likely to become a "tonnage" melting unit, but for the fairly continuous melting of alloy steel in small batches it will probably continue in the lead.

A newcomer to the field of electric steel melting made its appearance over a year ago, when the world's first mains frequency induction melting furnace for steel went into experimental production in Sheffield. Many doubts were expressed as to the wisdom of installing a mains frequency furnace for the melting of special steels, but the results achieved during the first year's working have been extremely good. The fundamental difference between high frequency and mains frequency melting lies in the tremendous turbulence which takes place in the latter, which makes it impossible to keep a slag covering on the surface of the bath. The critics felt that the slag constantly passing through the molten steel would leave highly detrimental non-metallic inclusions in the finished steel. In fact, the result has been the reverse of this expectation, and it is claimed that exhaustive tests have shown the cleanness to be superior to that attained with competitive commercial methods of melting special steels.

The capital cost of a mains frequency furnace is roughly half that of a similar high frequency installation, and the power consumption is claimed to be 20–30% better than other types of electric melting furnace of equivalent size up to 2 tons capacity. Lining life is said to be better than in the high frequency furnace, except when melting stainless steels in basic linings. When starting from cold a solid plug of metal is necessary, and in subsequent melts a molten heel of about 20% of the charge is left to facilitate rapid melting of the next heat. This has been found to make little difference to production costs, but it necessitates care in the order of melting when successive heats are to different specifications. Unlike its high frequency counterpart, the process is one calling for considerable skill on the part of the operatives.

In spite of developments in other aspects of electric melting, it seems likely that the unit of the future—as far as tonnage output is concerned—will be the oldest, the electric arc furnace. Until fairly recently, this process was mainly confined to the production of alloy and special steels in comparatively small furnaces. The position has changed substantially with the introduction of larger arc furnaces (40–200 tons capacity), and the bulk production of commercial grades of steel in successful competition with the non-electric steel making processes is now established.

The capital costs of an electric arc furnace steel plant are lower than for an open hearth plant of equivalent output, the most favourable size having a capacity of the order of 250,000 tons per annum. On the operating side, labour costs are similar and lining maintenance is probably cheaper, but the arc furnace has also to bear the cost of electrode usage, and anything that will reduce the figure of 13 lb./ton will be of the utmost value to the industry. The main factor in the economics of electric steel production is, however, the cost of power, and it is not surprising that electric melting has developed most rapidly in countries with ample sources of hydro-electric power. In other countries, the advent of nuclear power is likely to prove a factor of considerable significance.

It is possible that, in the future, the gap between pig iron and scrap prices will tend to close and thus eliminate a potential advantage of a cold metal melting unit. Furthermore, the improved quality of oxygen blown converter steels may involve the electric furnace in competition with a cheap hot metal process operating on low-cost pig iron. To meet this challenge there are a number of possible courses of action. For instance, oxygen injection may be used to speed up the melting of cold charges. A second possibility is the use of oxygen blown pre-refining vessels or hot blast cupolas to supply hot metal to the electric furnace. Finally, electric furnaces may be used in combination with other steel making units, such as oxygen blown converters.

Personal News

MR. V. HARBORD has retired from active partnership in the firm of Riley, Harbord and Law, consulting metallurgists and chemists, but will remain associated with it as a Consultant. The business will continue under the two existing Partners—MR. T. G. HOWARD and MR. R. J. HARBORD.

MR. G. R. BELL has resigned from Powder Metallurgy, Ltd., to become General Manager of the British Division of Wall Colmonoy (Canada), Ltd., a company interested in brazing alloys and hard facing alloys in the form of electrodes or powder.

DR. W. I. PUMPHREY has been elected to the Court of Governors of the University of Birmingham as a representative of the Guild of Graduates. Dr. Pumphrey is Manager of the Research Department of Murex Welding Processes, Ltd.

MR. R. D. BAIRD, a grandson of the founder, has been appointed a Director of Baird and Tatlock (London), Ltd., and of Hopkin and Williams, Ltd., and MR. R. T. BEASLEY has joined the B.T.L. Group of Companies as Personnel Manager.

ENGLISH STEEL CORPORATION, LTD., announces that MR. A. H. HIRD has been appointed to the Board of the company. Mr. Hird is a Director of Vickers, Ltd. and a number of its subsidiary companies, and has many past associations with English Steel Corporation, Ltd.

MR. J. H. OSBORN, Director of Samuel Osborn & Co., Ltd., Sheffield, together with MR. R. F. HORTON, Director and General Manager of Osborn Foundry & Engineering Co., Ltd., and MR. T. A. MARSDEN, Works Manager of Osborn Precision Castings, Ltd., have been awarded a Diploma by the Institute of British Foundrymen in recognition of their joint authorship of the paper entitled "A Modern Foundry for the Manufacture of Small Steel Castings by New Moulding Techniques."

MR. P. W. UNDERHILL, Chief Shipping Officer at Birlec, Ltd., has been appointed Chairman of the West Midlands Branch of the Institute of Export.

MR. G. C. ORAM, at present Manager of the Central Engineering Workshops at Appleby-Frodingham Steel Company, has been appointed to the new position of Works Manager (Production Services) from April 1st. This appointment follows from the re-grouping of certain activities which provide services to production, including the fuel department, engineering research, work study, water and oxygen supplies, and the pig casting machine. Mr. Oram will continue to act as Technical Consultant for Engineering Workshops to The United Steel Cos., Ltd., but responsibility for Appleby-Frodingham's Central Engineering Workshops will be transferred to MR. J. L. GASKELL, Chief Engineer. MR. F. J. WATTS will become Manager of the Workshops, MR. E. A. ATKIN is seconded as Acting Steelworks Engineer, and MR. R. H. SIDDONS joins Appleby-Frodingham from United Steel's Research and Development Department as Assistant Ironworks Engineer.

MR. W. A. HARTOP, Managing Director of George Kent, Ltd., sailed on April 2nd from Southampton for an extensive ten-weeks' business tour covering much of South Africa and the Federation of Rhodesia and Nyasaland.

MR. L. BAILEY has been appointed a Director of United Steel Structural Co., Ltd., Scunthorpe, a subsidiary of The United Steel Cos., Ltd.

MR. L. ROTHERHAM, Member for Research of the Central Electricity Generating Board, has been co-opted to the Council of the British Welding Research Association.

MR. W. H. MCFADZEAN, Chairman and Managing Director of British Insulated Callender's Cables, Ltd., has been elected President of the Federation of British Industries and took office last month.

MR. D. A. SENIOR has been appointed to the newly created post of Scientific Attaché to the British Embassy in Moscow. He will advise the British Ambassador (Sir Patrick Reilly) on scientific matters and report on Soviet scientific and technical development in the civil field. In taking up this appointment Mr. Senior joins the staff of the Department of Scientific and Industrial Research from the Royal Naval Scientific Service.

MR. R. D. HAMER has assumed the post of Chief Executive Officer for Aluminium, Ltd.'s international sales in Europe, Middle East and North Africa, with headquarters in Zurich. He was formerly Vice-President of Aluminium Laboratories, Ltd., in charge of the Banbury Research Laboratory and the company's Geneva Office.

MR. VERDON O. CUTTS, Manager of the Process Heating Department of The General Electric Co., Ltd., retired on March 31st. Mr. Cutts, a pioneer in the electrometallurgical field, started in business in Sheffield in 1909. Apart from his work as a consulting engineer, he specialised in electric furnaces and welding, and in 1929 he joined the G.E.C. and built up the Process Heating Department. Mr. Cutts will resume his consulting practice after March 31st from his home address: 1 Ramsay Lodge, Hillside Road, St. Albans.

IT is announced by Northern Aluminium Co., Ltd., that MR. E. L. ASHLEY, Manager of the Banbury Works for over quarter-of-a-century, has been appointed a Director of the company, and that the Board has accepted the resignation of MR. K. HALL, Assistant Director of Operations of the parent company, Aluminium, Ltd., Montreal, and a Director of Northern Aluminium since 1946. Mr. Ashley recently relinquished his position as Works Manager at Banbury, where he is succeeded by MR. C. I. F. MACKAY, Assistant Works Manager, to take up a special assignment connected with the establishment of a fabrication plant in New Zealand.

SIR EWART SMITH, F.R.S., has retired from the Board of Imperial Chemical Industries, Ltd. He joined Synthetic Ammonia and Nitrates, Ltd. (later the Billingham Division of I.C.I.) in 1923, becoming its Chief Engineer in 1932. After a period as Chief Engineer and Superintendent of Armament Design during the war, Sir Ewart returned to I.C.I. in 1945, when he was appointed Technical Director. At the time of his retirement Sir Ewart was Deputy Chairman of the company.

MR. G. H. ARMSTRONG has been appointed Chief Production Engineer for the Southern Works of the Crompton Parkinson Group of Companies, and MR. G. CUBITT-SMITH succeeds him as Production Engineer at Crompton Parkinson (Chelmsford), Ltd.

Note on the Prediction of Relaxation Stress-Time Curves from Static Tensile Test Data

By A. E. Johnson, D.Sc., M.Sc.Tech., M.I.Mech.E.,
J. Henderson, B.Sc., Grad.Inst.P., and V. D. Mathur, B.Sc.

Mechanical Engineering Research Laboratory, East Kilbride.

Static tensile and creep relaxation tests have been made on a magnesium alloy at 20° C., and the results analysed to examine the possibility of the prediction of relaxation stress-time curves on the basis of static tensile test data, and on the assumption of the existence of a mechanical equation of state. The results of these tests provide no evidence of the existence of such an equation of state for this material, and indicate that a reasonably close prediction of relaxation stress-time curves from static tensile test data is not possible.

Introduction

DURING past years, while much effort has been devoted to devising methods of prediction of relatively long period creep performance on the basis of short-term creep data, some attention has also been given to the possibility of predicting creep performance on the basis of the data afforded by static tensile tests at constant rates of total strain. For obvious reasons this is a particularly attractive possibility, and it has been examined by a number of investigators.

In all cases a tentative assumption of the existence of a mechanical equation of state* has been made to provide a link between metallic behaviour under creep conditions and in the static tensile test. Creep under relaxation conditions has not been dealt with. Opinion, however, seems to be somewhat mixed as to the validity of such an assumption of the existence of a mechanical equation of state, and in the following few paragraphs a summary is given of the course of recent work and views on this matter.

Zener and Holloman[1] and Nadai[3] initially proposed the idea of a mechanical equation of state for metals, and suggested a means of predicting creep strain-time curves from the stress-strain data of the static tensile test.

Holloman[2] advanced certain experimental evidence in support of the existence of a mechanical equation of state for metals, but Orowan[4] and Dorn and others[9] carried out tests, the results of which were certainly not in line with the conception in question.[4, 9]

Improved methods of predicting the creep strain-time curve from static tensile data were suggested by Pao and Marin[12], and also by Khosla and Findley,[13] and were applied to plastic materials, but not to metals. With some reservations, predictions in the case of these plastic materials proved relatively satisfactory.

Various parametrical relations between strain, strain rate, stress, time and temperature have been developed by McGregor and Fisher,[5, 6] Larsen and Miller,[7] Mansen and Haferd,[8] and Sherby, Orr and Dorn.[10, 11] The existence of a mechanical equation of state, even in an approximate sense, would enable the characteristics of tests of one type to be reasonably predicted from the results of tests of another type, making use of such parametrical relations, and it appears that this has actually been achieved in certain cases.

Under these circumstances, which on the whole appeared to correspond to a somewhat indecisive state of thought on this matter, the authors felt that it was worth while to examine for a number of engineering metals in a range of practical working temperatures, the possibility of predicting creep behaviour from the static tensile test on the basis of an assumption of a mechanical equation of state. Inasmuch as creep under relaxation conditions had not been considered in this regard by previous investigators, it was decided to examine the application of these ideas to the creep relaxation test in the first instance.

The present note describes the results of such an examination for the case of a magnesium alloy at 20° C. It is not intended to examine this material at any further temperature, although any additional materials will in general be examined at more than one temperature, provided such further examination is obviously worth while.

Scope of Investigation

A group of static tensile tests was made at constant total strain rates varying between 30×10^{-4} per hour and 2×10^{-4} per hour. On the basis of these static tests, predictions of the course of relaxation stress-time curves corresponding to a number of specific total strains were made, and these predictions compared with relaxation stress-time curves obtained in actual relaxation tests from corresponding initial total strains.

* i.e. an equation linking strain, strain rate, temperature and stress for all varieties of test.

TABLE I.—DETAILS OF PRODUCTION, HEAT TREATMENT AND COMPOSITION OF THE MAGNESIUM ALLOY

Details of Production and Dimensions	Details of Heat Treatment	Details of Chemical Composition (%)						
		Zn	Al	Si	Cu	Mn	Fe	Sn
Continuously cast billets of length 12 in. and diameter 12 in.	420° C. ± 5° C. for 4 hours, furnace cooled to room temperature in about 10 hours. Heat treatment carried out in an atmosphere of sulphur dioxide.	<0·05	2·0	0·02	<0·01	0·03	<0·04	<0·05

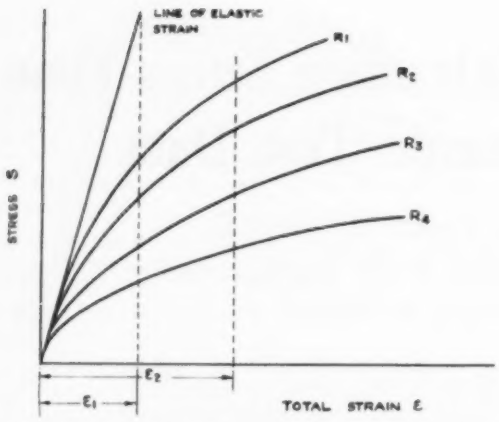

Fig. 1.—Family of stress-strain curves for static tensile tests at constant rates of total strain.

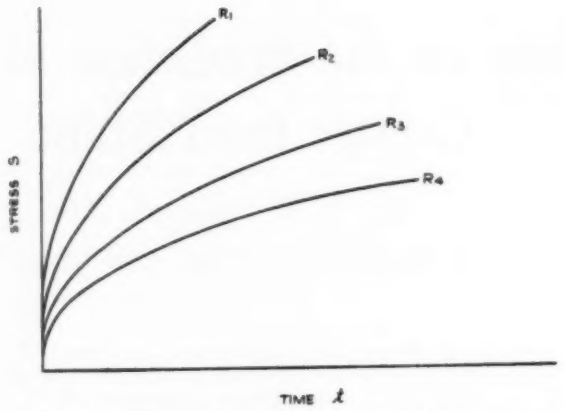

Fig. 2.—Family of stress-time curves for static tensile tests at constant rates of total strain.

Details of Materials, Specimens and Testing Techniques

Details of the composition, production and heat treatment of the magnesium alloy are given in Table I.

The testing machine used in the static tensile tests was a single lever tensile testing machine of 10-tons loading capacity, capable of straining at constant rates of minimum values of 10^{-4} per hour. The duration of most of the static tensile tests was seven hours, but one exceeded this length of time. Records of total strain, load and time were made as each increment of applied load was balanced.

The creep relaxation tests were made in a Denison 5-ton creep testing unit and were of duration 3-6 hours. Records of relaxed stress were taken at frequent intervals during the course of these tests.

In both static tensile tests and creep relaxation tests a Martens-type extensometer was used to record strain, and a standard 0·357 in. diameter creep test piece was used.

Results of Static Tensile and Creep Relaxation Tests

In Fig. 4 a family of static tensile stress-total strain curves is shown for the range of total strain rates involved. In Fig. 5 stress-time curves corresponding to the stress-strain curves are shown. Fig. 6 shows the relation between various values of the slope dt/dS of these stress-time curves and the stress, for a series of specific values of initial total strain. Fig. 7 shows a family of relaxation-time curves obtained by graphical integration from Fig. 6, while in Figs. 8 to 11, comparison is made between several of these computed curves for values of particular initial total strains, with actual relaxation-time curves obtained in the creep testing machine. Figs. 1, 2 and 3 are figures generally descriptive of the method of deriving creep relaxation-time curves from static tensile test data.

Discussion

If the conception of a mechanical equation of state be valid for the current material, a general differential equation may be taken to hold for all varieties of test, i.e. static tensile, creep and relaxation at a particular temperature, viz.

$$R = \frac{d\epsilon_t}{dt} = \frac{d\epsilon_{el}}{dt} + \frac{d\epsilon_c}{dt} = \frac{1}{E}\left(\frac{dS}{dt}\right) + C$$

where ϵ_t represents total strain, R the total strain rate, ϵ_{el} the elastic strain, ϵ_c creep or plastic strain, S the stress at time t, and C the corresponding creep rate.

Considering in particular the relations between the static tensile and relaxation tests, we note that under the conditions of the relaxation test the total strain ϵ_t remains constant at the value of (say) ϵ_1 and, accordingly,

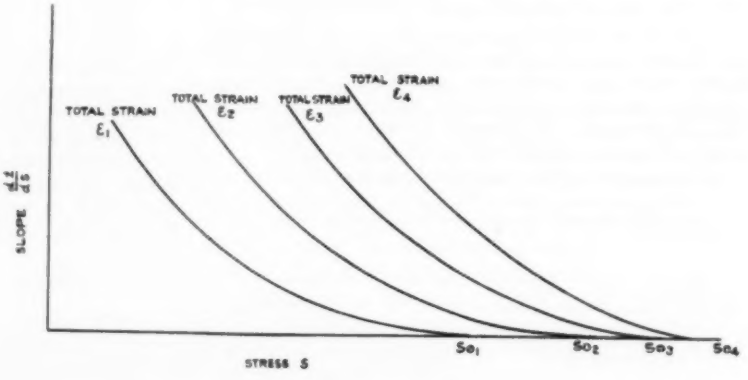

Fig. 3.—Curves of stress (S) v slope (dt/dS), where t is time.

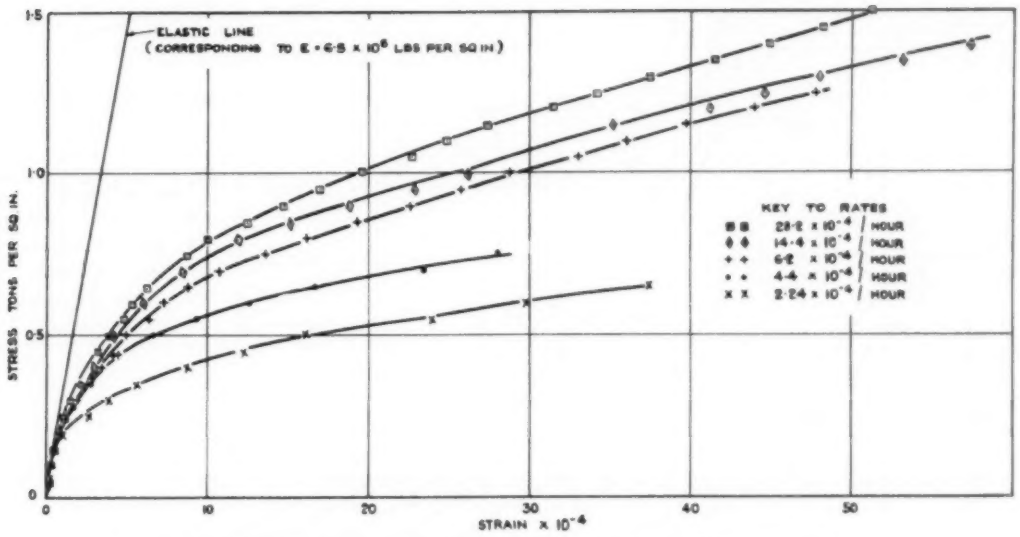

Fig. 4.—Stress-strain curves for static tensile tests at constant total strain rates.

$d\epsilon_t/dt=0$. Under these circumstances the above differential equation reduces to :—

$$C = -\frac{1}{E}\cdot\frac{dS}{dt}$$

The equation thus gives the creep rate C, which corresponds in the relaxation test to a specific relaxed stress S and an initial total strain of ϵ_1.

Consider Fig. 1, showing stress plotted against total strain for various rates of strain R_1, R_2, etc., in the static tensile tests. For the value of total strain under consideration (ϵ_1), we have a series of values of stress corresponding to the various rates R_1, R_2, etc. Let these values be S_1, S_2, etc. The plastic or creep strains corresponding to these values of stress are given in each case by subtracting from ϵ_1 the elastic strain S/E, which is given by the intercept corresponding to S on the elastic line in Fig. 1, i.e. the plastic or creep strain is $[\epsilon_1-S/E]$. Accordingly, corresponding to the specific total strain ϵ_1, we have a series of stresses S and a corresponding series of creep and plastic strains $[\epsilon_1-S/E]$. This, of course, is also the case in the relaxation tests, where for each relaxed stress S, the creep or plastic strain portion of the total strain would again have the value $[\epsilon_1-S/E]$, the total strain retaining the value ϵ_1.

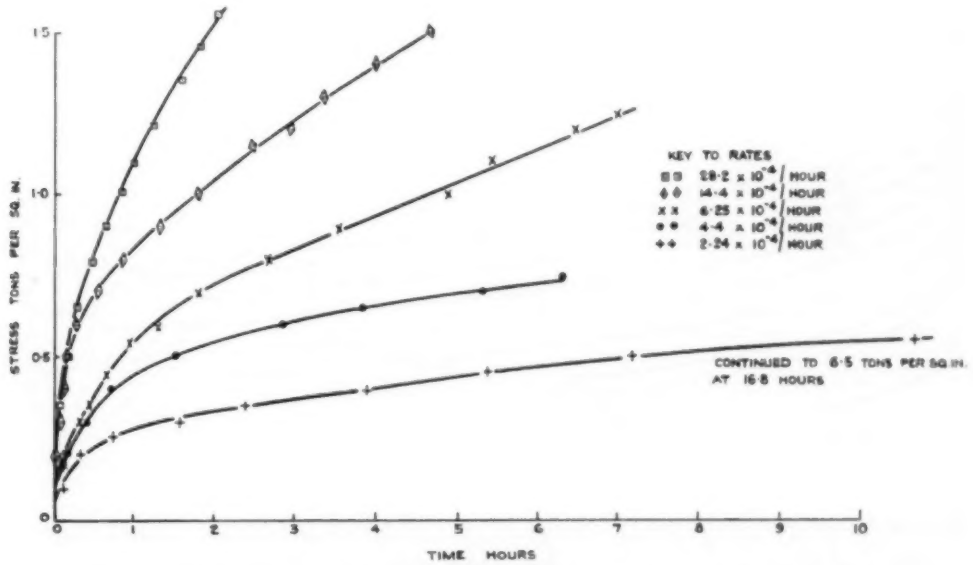

Fig. 5.—Stress-time curves for static tensile tests at constant total strain rates.

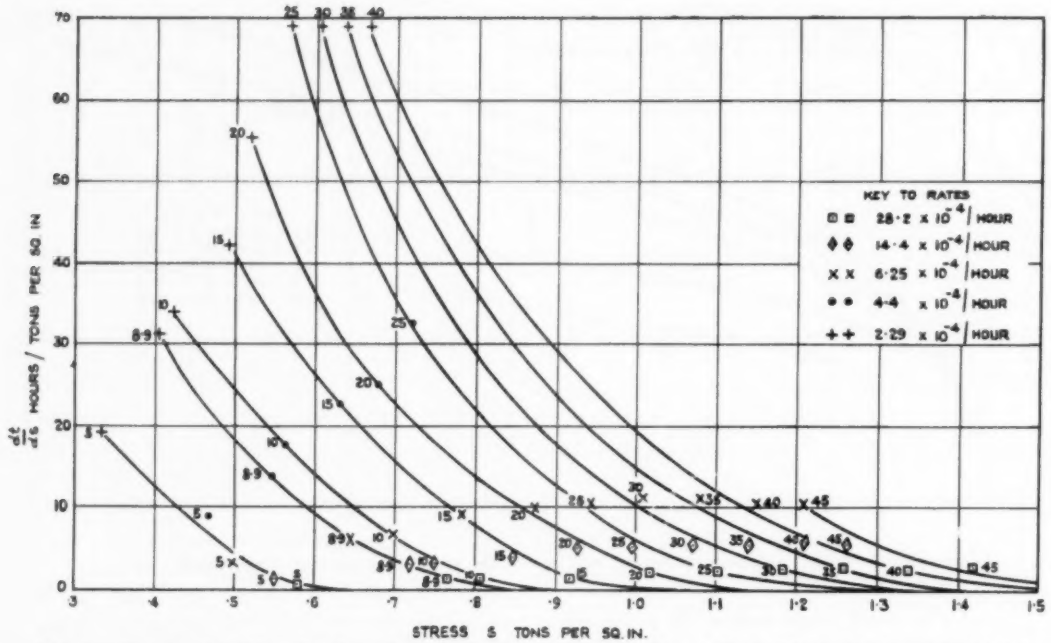
KEY TO RATES
28·2 x 10⁻⁴ / HOUR
14·4 x 10⁻⁴ / HOUR
6·25 x 10⁻⁴ / HOUR
4·4 x 10⁻⁴ / HOUR
2·29 x 10⁻⁴ / HOUR
dt/dS HOURS / TONS PER SQ IN
STRESS S TONS PER SQ IN.

Fig. 6.—Curves of dt/dS v. S, where S is stress and t is time in the static tensile tests at constant total strain rates. The figures on the curves are the total strains $\times 10^{-4}$ for various stresses.

If a mechanical equation of state exists, then corresponding to each specific stress S, and the corresponding plastic or creep strain $[\epsilon_1 - S/E]$, there is a specific creep rate which would have the same value in both the static tensile and the relaxation tests. Accordingly, we may ascertain the creep rates occurring at specific relaxed stresses in the relaxation test by determining the corresponding rates in the static tensile tests.

In Fig. 2 are shown curves of stress-time for the series of total machine rates R_1, R_2,* etc., and accordingly our required rates are obtained by taking the slope dS/dt in Fig. 2 for each of the points of intersection of the total strain lines ϵ_1 in Fig. 1 with each of the curves in that Figure corresponding to R_1, R_2, etc., i.e. dS/dt is taken in Fig. 2 for each of the values of S on each curve corresponding to R_1, R_2, etc.

* These curves may either be obtained from Fig. 1 by conversion of total strain using the values of constant rates R_1, R_2, etc., or by direct observation of time in the tests.

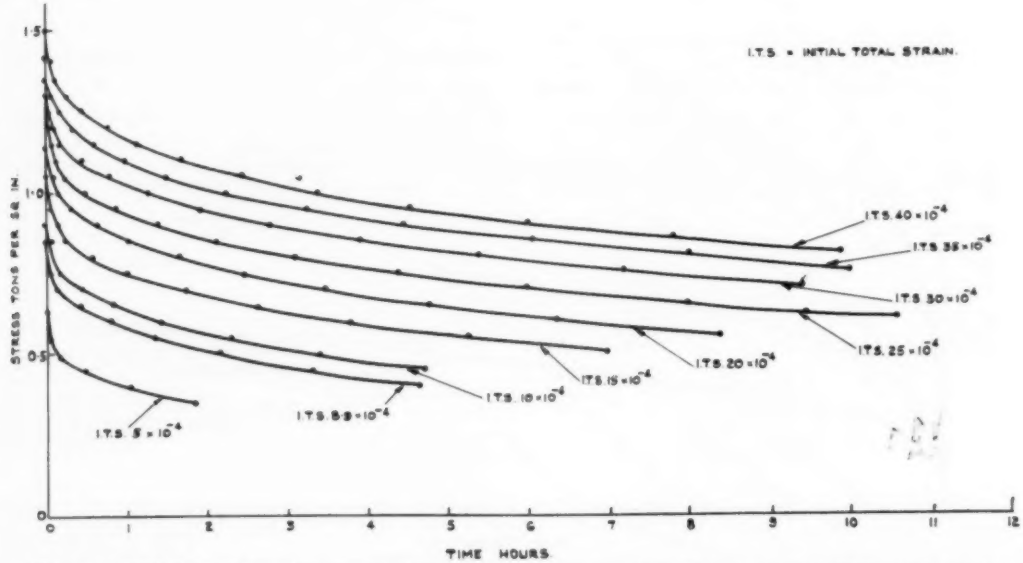
I.T.S. = INITIAL TOTAL STRAIN.
I.T.S. 40 x 10⁻⁴
I.T.S. 35 x 10⁻⁴
I.T.S. 30 x 10⁻⁴
I.T.S. 25 x 10⁻⁴
I.T.S. 20 x 10⁻⁴
I.T.S. 15 x 10⁻⁴
I.T.S. 10 x 10⁻⁴
I.T.S. 8·9 x 10⁻⁴
I.T.S. 5 x 10⁻⁴
STRESS TONS PER SQ IN
TIME HOURS

Fig. 7.—Predicted relaxation stress-time curves for a number of values of initial total strain.

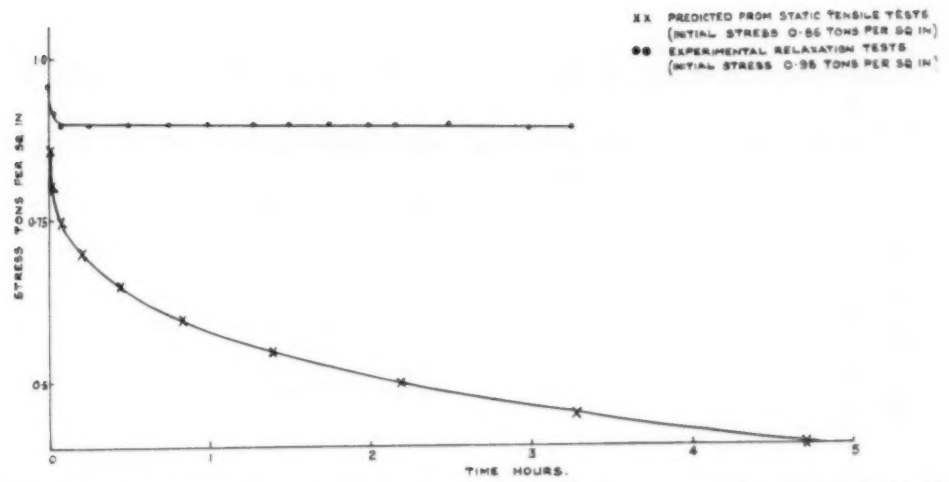

Fig. 8.—Predicted and experimental relaxation stress-time curves from an initial total strain of 0·0009.

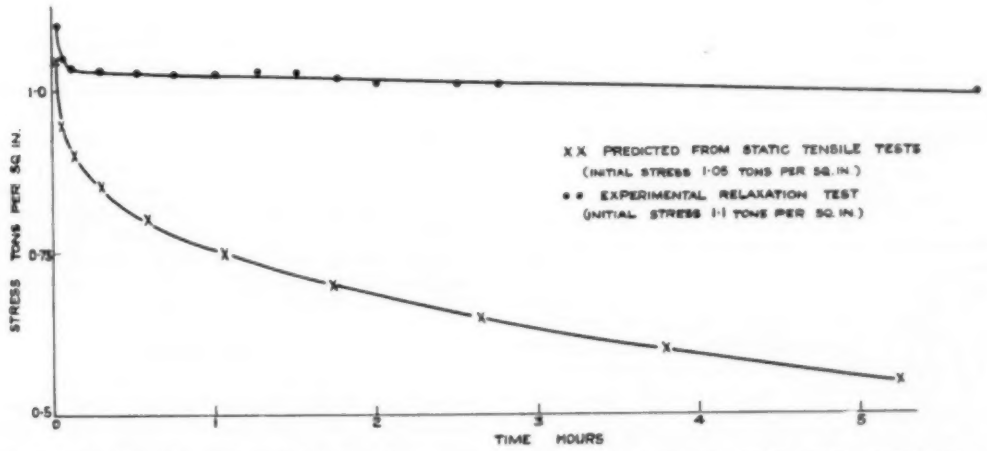

Fig. 9.—Predicted and experimental relaxation stress-time curves from an initial total strain of 0·0015.

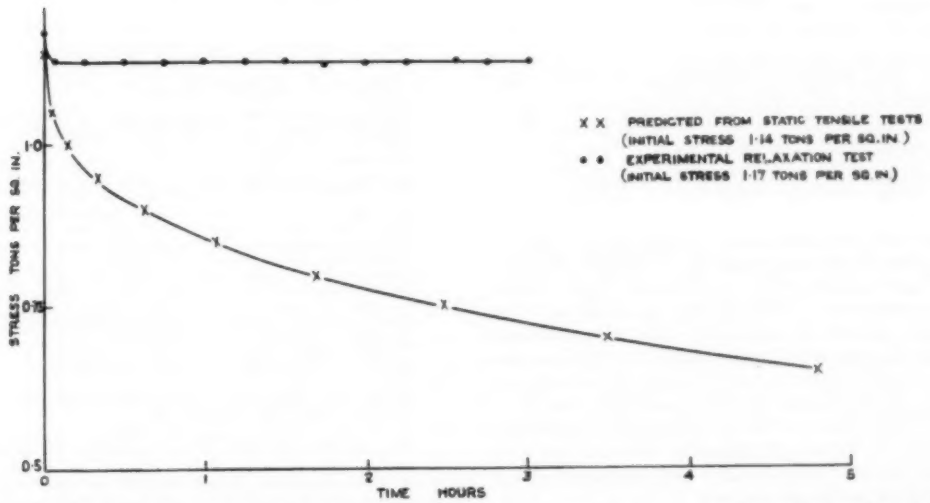

Fig. 10.—Predicted and experimental relaxation stress-time curves from an initial total strain of 0·0020.

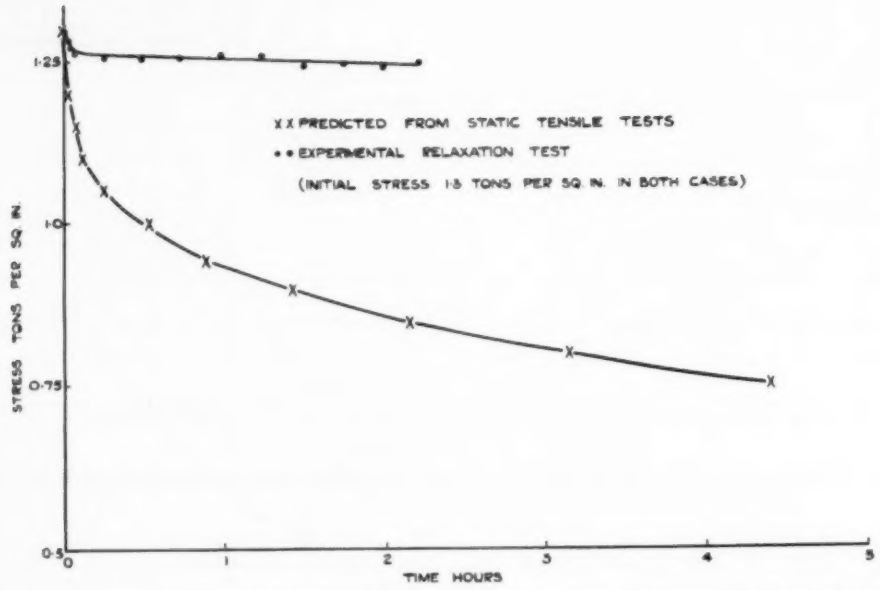

Fig. 11.—Predicted and experimental relaxation stress-time curves from an initial strain of 0·0025.

We thus obtain a series of creep rates

$$C = -\frac{1}{E}\cdot\frac{dS}{dt}$$

corresponding to a series of stresses S and a constant total strain ϵ_1.

We then plot $1/C$, which of course $= -E dt/dS$ against S/E or, equally well, $-dt/dS$ against S, as shown generally in Fig. 3. Integrating the area under the curve in Fig. 3 gives the elapsed time to reach specific stresses, and hence the S v. t curve for relaxation, providing a mechanical equation of state holds. The limits of the graphical integration are S and S_0, where S_0 is the stress at which each curve cuts the axis of S. The process may of course be repeated for further total strains ϵ_2, ϵ_3, etc.

The application of these methods to the results of the current tests is indicated in Figs. 4, 5 and 6, where the respective stress-strain, stress-time and dt/dS v. S curves are shown. The results of integration for initial total strain between 5×10^{-4} and 40×10^{-4} are shown in the family of curves in Fig. 7, and the curves for initial total strains of 9, 15, 20 and 25×10^{-4} are shown in Figs. 8–11 compared with the experimental results of relaxation tests actually made in the Denison creep machine.

It is noted that the relaxation of stress taking place in a specific period, in the case of all the predicted relaxation curves, is very considerably in excess of that actually found by experiment. This applies to all initial total strains. It is also to be remarked that the maximum stresses reached upon loading the experimental relaxation tests, were, in all but one case, very close to the values of the stresses S_0 indicated by the predicted curves of dS/dt v. S. This is in a sense fortunate, as it underlines the fact that the stress commencing from virtually the same values in the experimental and predicted curves follows a greatly different course.

In the light of the above facts, it seems obvious that, for this material and temperature, assumption of the existence of a mechanical equation of state linking static tensile tests with creep or creep relaxation tests is without any real justification, even as an approximation, and accordingly any phenomenological or parametrical relation which may be used in conjunction with or implying such an assumption cannot hope to correlate static tensile and relaxation tests.

Conclusion

The results of the static tensile and relaxation tests carried out on the magnesium alloy at 20° C. provide no evidence of the existence of a mechanical equation of state for this material, and indicate that a reasonably close prediction of relaxation stress-time curves from the static tensile data is not possible.

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The Low-Temperature Mechanical Properties of Some Cast Stainless Steels

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The tensile and impact properties of several cast austenitic stainless steels, at temperatures between 100° C. and −196° C., are presented. The tensile properties are inferior to those of the corresponding types of wrought steel, but the cast materials still provide good ductility values at low temperatures. At all temperatures the impact properties of the cast stabilized steels, and at low temperatures those of the non-stabilized steels, are higher the lower their carbon contents. At temperatures as low as −196° C., Charpy V-notch impact values of about 40 ft. lb. and 70 ft. lb., respectively, can be obtained in cast stabilized and non-stabilized steels of the 18Cr/8Ni types containing 0·05–0·06% carbon.

USE of chromium-nickel austenitic steels for applications involving low temperatures is well established: in addition to being corrosion-resistant, these steels retain much of their room-temperature ductility and toughness at sub-zero temperatures, and do not undergo the marked deterioration in impact-resistance shown by ferritic steels over certain temperature ranges. However, much of the information given in the literature on the low-temperature tensile and impact properties of stainless steels is concerned with materials in the wrought condition.[1-3] There are also some data on such steels in welded form,[4] but comparatively little has been published on the mechanical properties of cast stainless steels. Reference may, however, be made to data obtained by Juppenlatz[5] on cast material from normal production heats, the impact properties being reported as Charpy keyhole-notch values.

The aim of the present investigation was to assess the relative merits of a few types of cast stainless steel on the basis of their tensile and impact properties at sub-zero temperatures. The data were obtained mainly on laboratory heats, but the impact properties and microstructures of commercially-produced test castings of two types of steel were also examined. Several of the steels were stabilized with niobium and one titanium-stabilized steel was also included.

Experimental Procedure

The laboratory steels were produced as 100-lb. melts in a high-frequency furnace, and with one exception were sand-cast as standard four-leaf clover test-blocks, each leaf being 1½ in. diameter and 9 in. long. The low-carbon 18Cr/8Ni steel *C* (Table I) was cast as keel type test blocks 9 in. long × 1 in. wide × 1½ in. deep. The castings, after removal of the feeder heads, were heated at 1,050° C. for four hours and water-quenched. The limbs of the clover castings were then sectioned into blanks for the provision of 0·252 in. diameter tensile test-pieces and 10 × 10 × 60 mm. Charpy V-notch impact specimens. On each Charpy specimen the 2 mm. deep, 0·25 mm. root radius, V-notch was machined on the side which had been nearest to the surface of the clover casting. Charpy impact specimens only were machined from the keel blocks, and the V-notch was placed on the side of each test-piece which had been farthest away from the feeder head. The tensile properties were determined in duplicate at 20° C., −78° C. and −196° C., and the impact tests were made on a 215 ft. lb. Charpy machine at temperatures between 100° C. and −196° C. The specimens were cooled to sub-zero temperatures in ligroin to which pieces of solid carbon dioxide were added (0 to −78° C.), in isopentane cooled with liquid nitrogen (−78 to −196° C.), or in liquid nitrogen (−196° C.). Each specimen was held in the appropriate cooling medium for a minimum period of 10 minutes prior to test. Impact-test data, on keel test-blocks from three commercial heats, representing two types of steel, were supplied by the makers.

Test Results

Analyses of the steels are given in Table I and the results of the tensile tests are shown in Table II. Some degree of scatter between the results of the duplicate tests may be observed, but no unsoundness was detected in any of the test-pieces. In general, the tensile strengths of the cast steels were lower at all temperatures than

TABLE I.—COMPOSITIONS OF THE CAST STAINLESS STEELS.

Steel	Source	Analysis (Wt. %)									
		C	Si	Mn	S	P	Ni	Cr	Mo	Ti	Nb
A	Laboratory	0·14	0·38	0·53	0·014	0·017	8·4	18·0	—	—	—
B	Commercial	0·11	0·70	0·90	—	0·022	8·5	18·6	—	—	—
C	Laboratory	0·06	0·37	0·52	0·007	0·013	8·4	17·8	—	—	—
D	Commercial	0·12	0·72	0·83	0·032	—	8·4	18·4	—	—	0·94
E	Laboratory	0·11	0·46	0·50	0·012	0·017	9·8	17·7	—	—	1·27
F	Commercial	0·12	0·74	0·83	—	—	10·0	18·4	—	—	0·75
G	Laboratory	0·055	0·57	0·48	0·010	0·025	10·1	18·1	—	—	0·50
H	Laboratory	0·12	0·44	0·51	0·009	0·018	9·4	17·7	3·29	—	—
I	Laboratory	0·10	0·54	0·49	0·010	0·015	11·4	16·9	2·55	0·55	—

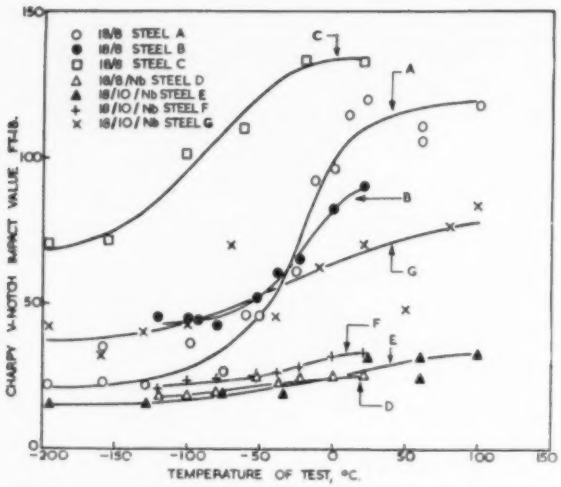

Fig. 1.—Impact properties of the cast 18Cr/8-10Ni steels water-quenched from 1,050° C.

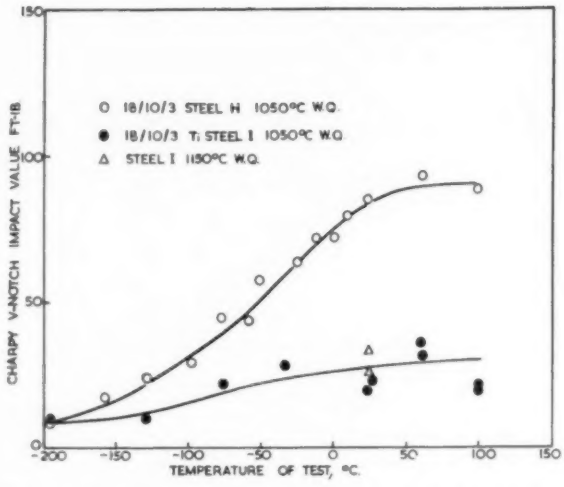

Fig. 2.—Impact properties of the cast 18Cr/10Ni/3Mo steels.

those normally obtained from wrought steels of similar compositions, and at sub-zero temperatures the ductility of the cast steels was also inferior to that of their wrought counterparts. Localized "necking" frequently occurred at several places along the length of the test-piece, and at the point of final fracture the section was often so distorted that reduction-in-area could not be measured in the conventional manner.

It is interesting to note that at all test-temperatures the elongation values for the low-carbon 18/10/0·5 niobium steel *G* were higher than those of the higher carbon 18/10/1 niobium steel *E*. As will be shown later, this difference may be attributable to the different niobium carbide contents of the two steels.

The impact properties of the laboratory-made and commercial steels are shown in Figs. 1 and 2. The niobium- and titanium-stabilized steels containing about 0·1% carbon gave relatively low impact values at all temperatures, but the lower-carbon 18/10/0·5 niobium steel *G* showed appreciably greater impact strength, and at −196° C. an impact value of 40 ft. lb. was obtained from this steel. The non-stabilized 18Cr/8Ni steels

TABLE II.—TENSILE PROPERTIES OF THE LABORATORY-MADE CAST STAINLESS STEELS.

Steel	Temperature of Test (° C.)	0·1% Proof Stress (tons/sq. in.)	0·2% Proof Stress (tons/sq. in.)	0·5% Proof Stress (tons/sq. in.)	Ultimate Tensile Stress (tons/sq. in.)	Elongation on $4\sqrt{\text{Area}}$ (%)	Reduction of Area (%)
Steel *A*	20	14·3 14·0	15·0 14·4	15·9 15·6	33·4 33·4	52 62	— —
18Cr/8Ni 150 D.P.N.	−78	14·4 13·8	15·8 15·2	16·8 16·6	48·0 45·0	18 17	— —
	−196	16·8 16·6	18·4 18·0	20·2 19·8	40·0 44·4	11 —	12 —
Steel *E*	20	13·8 14·0	14·6 15·0	15·6 16·2	33·2 32·8	34 —	— —
18Cr/10Ni/1Nb 176 D.P.N.	−78	10·4 8·0	11·8 10·0	15·0 13·2	51·2 53·6	18 20	— —
	−196	10·2 9·5	13·3 12·7	18·0 17·6	63·6 60·4	11 12	7 11
Steel *G*	20	12·7 12·7	13·5 13·5	14·3 14·3	30·4 31·0	57 52	— —
18Cr/10Ni/½Nb 138 D.P.N.	−78	12·2 11·4	13·4 12·8	15·5 14·5	62·0 51·0	38 —	29 —
	−196	10·4 10·2	13·8 13·4	19·9 19·2	75·2 77·6	23 23	19 18
Steel *H*	20	15·7 16·4	16·3 17·2	17·8 18·8	34·1 33·4	49 35	— —
18Cr/10Ni/3Mo 188 D.P.N.	−78	22·2 22·2	23·2 23·4	24·8 24·7	37·6 51·0	20 33	— —
	−196	30·8 29·4	33·4 31·4	36·0 33·4	57·0 57·2	18 30	17 15
Steel *I*	20	15·2 14·0	16·0 15·2	17·2 16·6	29·2 32·4	30 42	— —
18Cr/10Ni/3Mo/½Ti 164 D.P.N.	−78	18·0 14·8	19·6 17·0	22·6 19·8	29·6 42·4	11 34	23 32
	−196	18·0 19·0	19·8 21·4	22·0 24·4	41·0 61·0	15 23	— —

Fig. 3.—Microstructure of 18/8 Steel A, annealed 1,050° C. and water-quenched. Electrolytically etched in 8% oxalic acid. × 100

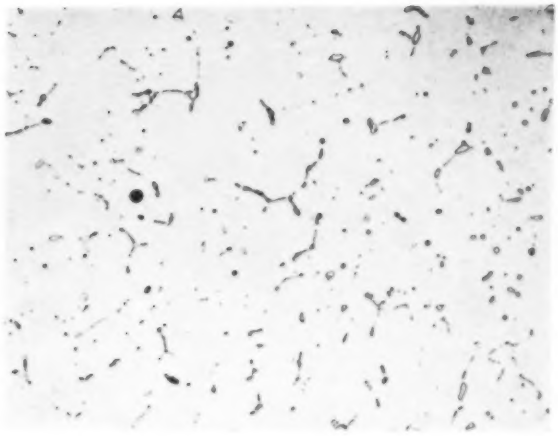

Fig. 4.—Microstructure of 18/8 steel B, annealed 1,050° C. and water-quenched, showing δ-ferrite and discontinuous chains of carbides. Electrolytically etched in 8% oxalic acid. × 100

(*A*, *B* and *C*, Fig. 1) were markedly superior to the niobium-stabilized steels at room temperature, giving impact values only slightly less than those usually obtained with wrought 18/8 steels. However, the impact values of the non-stabilized cast 18/8 steels fell sharply with decrease of temperature below zero, and at low temperatures steel *A*, which had the highest carbon content (0·14%), appeared to be little better than the 0·1% carbon niobium-containing steels. On the other hand, the low-carbon 18/8 steel *C* showed a high level of impact strength even at temperatures as low as −196°C.

The impact values of the non-stabilized 18/10/3 molybdenum steel *H* also showed a marked fall with decrease of temperature, and in this type of steel the addition of a stabilizing element again had the effect of seriously impairing the room-temperature impact properties (Fig. 2).

Results of Microscopic Examination

The microstructure of the 18/8 steel containing 0·14% carbon (steel *A*) showed a fine network of grain-boundary carbide and small clusters of interdendritic carbides (Fig. 3), whilst that of the 0·11% carbon steel *B* showed a small amount of δ-ferrite and interdendritic discontinuous chains of carbide particles (Figs. 4 and 5). As may be expected, the 0·06% carbon steel *C* contained a greater amount of δ-ferrite than steel *B* and fewer carbide particles (Fig. 6).

All the niobium-stabilized steels contained varying amounts of an interdendritic eutectic, as shown in Figs. 7, 8 and 9. The microstructure of steel *F* was similar to that of steel *D* and is therefore not illustrated. An X-ray examination of carbide extracts of one of these steels indicated the predominant carbide to be niobium carbide, and it appears that the eutectic comprises this phase and austenite. It will be noted that the higher the carbon and niobium contents of the steels the greater is the amount of carbide eutectic present. Some differences among the ferrite contents of the various niobium-stabilized steels were also observed.

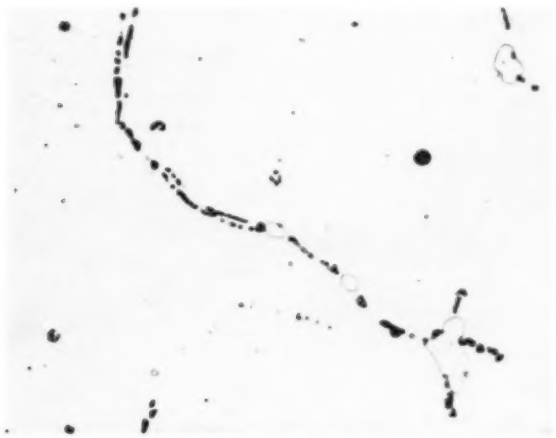

Fig. 5.—Microstructure of the same specimen as that shown in Fig. 4, but at a higher magnification. × 500

Fig. 6.—Microstructure of 18/8 steel C, annealed 1,050° C. and water-quenched. Electrolytically etched in 8% oxalic acid. × 500

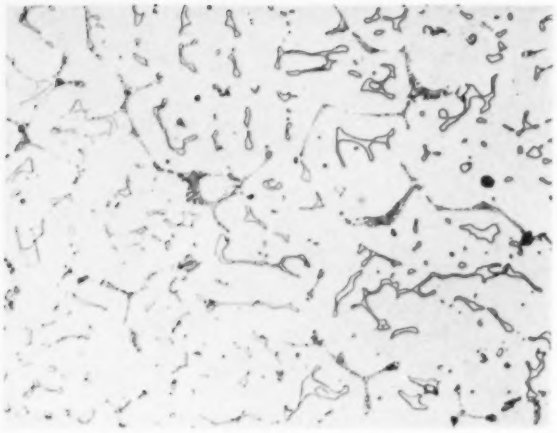

Fig. 7.—Microstructure of 18/8/Nb steel D, annealed 1,050° C. and water-quenched, showing δ-ferrite and interdendritic carbide eutectic in austenitic matrix. Electrolytically etched in 8% oxalic acid. × 100

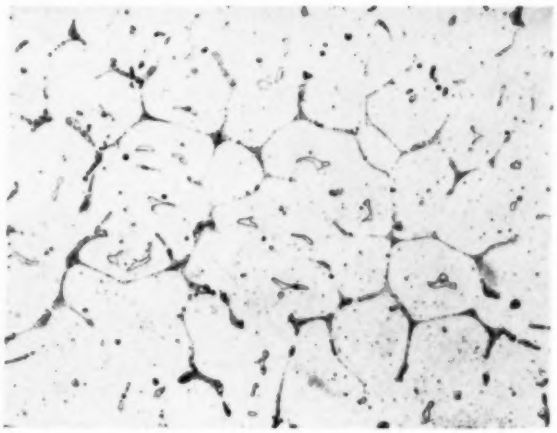

Fig. 8.—Microstructure of 18/10/Nb steel E, annealed 1,050° C. and water-quenched: contains less δ-ferrite than steel D, but the amount of carbide eutectic is similar. Electrolytically etched in 8% oxalic acid. × 100

The microstructures of the 18/10/3 molybdenum steel *H* showed interdendritic areas of δ-ferrite (Fig. 10) with small carbide and σ crystals at the boundaries of these areas (Fig. 11).

In the titanium-stabilized 18/10/3 molybdenum steel, water-quenched from 1,050° C., δ-ferrite was retained at the cores of the dendrites, whilst titanium carbide, titanium nitride, σ-phase and ferrite were present in the interdendritic areas (Figs. 12, 13 and 14). In view of the more extensive σ-formation in this steel, it was thought that its relatively poor impact properties could be ascribed to the presence of this brittle phase, but after annealing and water-quenching from 1,150° C., although the σ was replaced by ferrite (Fig. 15), the impact value at room temperature remained virtually unchanged, as indicated in Fig. 2.

Discussion

The tensile properties of the cast stainless steels were inferior to those normally obtained for wrought steels of comparable compositions. It will be noted that the tensile strength of steel *A* was slightly lower at −196° C. than at −78° C., whereas in all other cases as the test-temperature was lowered higher maximum stress values were obtained. Microscopic examination of the broken tensile test-piece of steel *A*, tested at −196° C., showed that the fracture had occurred entirely along the grain boundaries. It appeared, therefore, that the almost continuous network of carbide in this steel had lowered the grain boundary fracture strength, and that at low temperatures this was below the fracture strength of the matrix.

The low-temperature impact properties of the higher-carbon cast stainless steels were also inferior to those of their wrought counterparts, and the sharp fall in impact values of many of the cast steels with lowering of temperature suggests that the austenite matrix is less stable than in wrought steels. A microscopic examination of

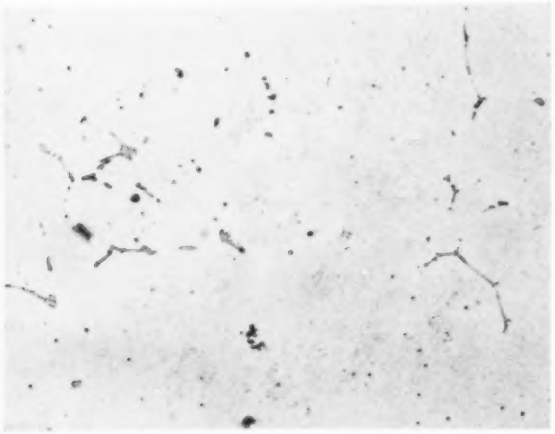

Fig. 9.—Microstructure of 18/10/Nb steel G, annealed 1,050° C. and water-quenched: contains less carbide eutectic than steels D and E. Electrolytically etched in 8% oxalic acid. × 100

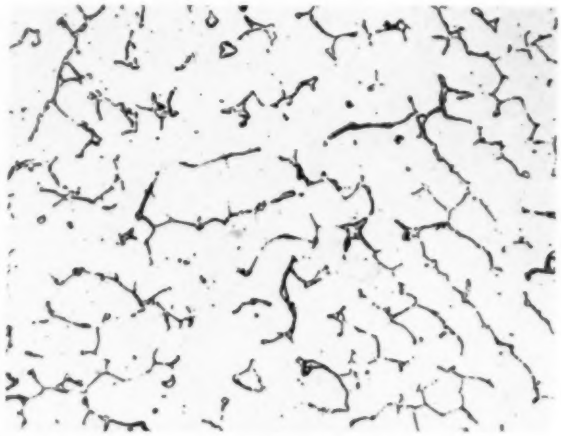

Fig. 10.—Microstructure of 18/10/3Mo steel H, annealed 1,050° C. and water-quenched: interdendritic δ-ferrite, sigma-phase and carbide in austenitic matrix. Electrolytically etched in 8% oxalic acid. × 100

Fig. 11.—Microstructure of the same specimen as that shown in Fig. 10, but at a higher magnification. × 750

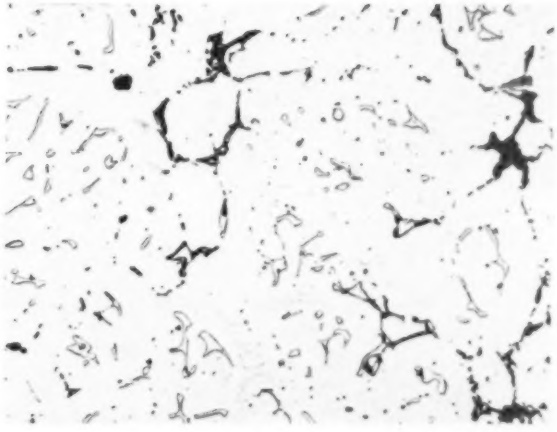

Fig. 12.—Microstructure of 18/10/3/Ti steel I, annealed 1,050° C. and water-quenched: δ-ferrite at cores of dendrites and dark-etching interdendritic phases. Electrolytically etched in 8% oxalic acid. × 100

the impact test-pieces broken at low temperatures revealed the presence of martensite in the vicinity of the fracture surfaces, this constituent being formed under the combined influence of low temperature and plastic strain. The high impact values of the low-carbon 18/8 steel *C* at low temperatures can be ascribed to the greater impact strength of the low-carbon martensite which would be formed in such a steel.

The poorer impact properties, at all temperatures, of the niobium-stabilized steels *D*, *E* and *F*, compared with those of steel *G*, are undoubtedly due to their higher carbon and niobium contents and the presence of eutectic carbide in the cast structures. The formation of interdendritic strings of titanium carbide in the titanium-stabilized 18/10/3 molybdenum steel *I* has a similar effect, and presumably the impact properties of that steel also would be improved if the carbon and titanium contents were lower.

In general the results of this investigation have indicated that various types of cast stainless steel possess good tensile ductility at temperatures as low as −196° C., and that, if carbon contents and the requisite stabilizing additions are maintained at relatively low levels, the steels also give low-temperature impact values of a high order. Thus, in non-stabilized steels of the 18/8 type, Charpy V-notch impact values of about 70 ft. lb. can be obtained at −196° C., whilst values of about 40 ft. lb. are possible at this temperature with stabilized steels of similar type. These properties, in comparison with those of other cast materials, establish cast stainless steel as an important material for low-temperature service.

The extent to which low carbon contents are likely to be achieved in commercial practice will obviously depend on factors such as the melting procedure used and associated production costs, whilst the retention of good castability must also be borne in mind. The nickel contents of cast stainless steels should also be somewhat

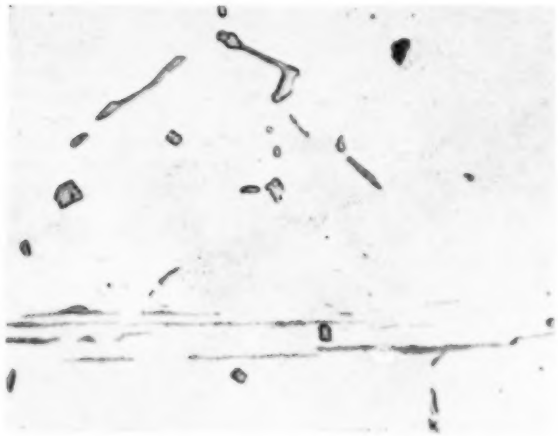

Fig. 13.—Microstructure of 18/10/3/Ti steel I, annealed 1,050° C. and water-quenched, showing elongated titanium carbide and cuboids of titanium nitride in the interdendritic areas seen in Fig. 12. Unetched. × 750

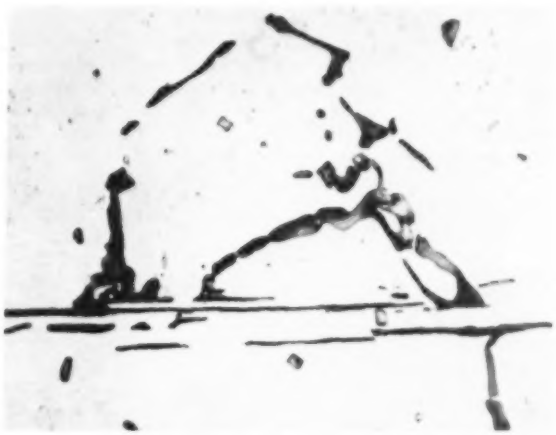

Fig. 14.—Microstructure of 18/10/3/Ti steel I, annealed 1,050° C. and water-quenched, showing sigma-phase associated with the interdendritic titanium carbide and nitride. Electrolytically etched in 8% oxalic acid. × 750

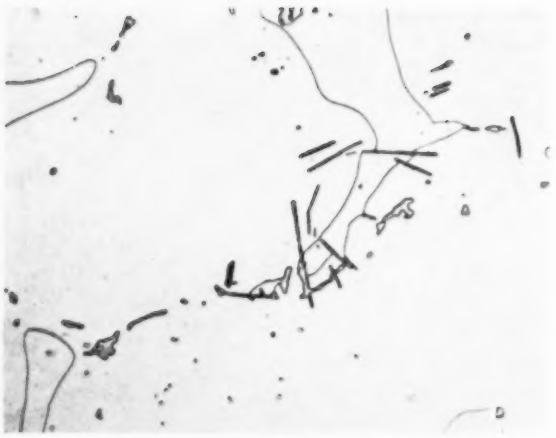

Fig. 15.—Microstructure of 18/10/3/Ti steel I, annealed 1,150° C. and water-quenched: sigma-phase is replaced by δ-ferrite after quenching from the higher temperature. Electrolytically etched in 8% oxalic acid. × 500

higher than in comparable types of wrought steel, in order to promote greater stability of the austenite, and thus counteract the effects of inhomogeneity on structural stability, which may be impaired locally, causing reduced ductility and toughness at low temperatures.

Conclusions

Cast 18Cr/8N isteels containing 0·1–0·14% C provide, in the annealed condition, a useful combination of tensile and impact properties for low-temperature applications. At room-temperature, maximum stress values of about 33 tons/sq. in., elongation of 50–60%, and Charpy V-notch impact values of 90–120 ft. lb. are obtained; at −196° C., the ductility remains relatively high (10%, or more) and impact values of 20–45 ft. lb. can be expected. The low-temperature impact properties are further improved if the carbon content is maintained at a relatively low level, values of about 70 ft. lb. being obtained at −196° C. for steels containing 0·05–0·06% carbon.

Cast stabilized stainless steels, containing about 0·1% carbon, give similar tensile properties to those of the non-stabilized steels, but their impact values are lower at room-temperature. However, the impact properties are also improved if the carbon content, and the corresponding stabilizing additions, are reduced. Thus, values of about 40 and 70 ft. lb., respectively, are obtained at −196° C. and 20° C. in steels of the 18Cr/10Ni/Nb type containing 0·05–0·06% carbon.

Acknowledgments

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New and Revised British Standards

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B.S. 512. Hot Finished Seamless Mild Steel Boiler and Superheater Tubes.
B.S. 1652. Seamless 0·5% Molybdenum Steel Boiler and Superheater Tubes.
B.S. 1653. Seamless Chromium-Molybdenum Steel Boiler and Superheater Tubes.
B.S. 1654. Electrically Welded Mild Steel Boiler and Superheater Tubes.
B.S. 1678. Cold Drawn Electrically Welded Mild Steel Boiler and Superheater Tubes.

Additionally—to meet the needs of industry—the single volume contains requirements for hot finished seamless and cold drawn seamless carbon steel boiler and superheater tubes (27 tons/sq. in. minimum tensile strength); and for hot finished seamless and cold drawn seamless 2¼% chromium, 1% molybdenum steel boiler and superheater tubes (27 or 31 tons/sq. in. minimum tensile strength).

The standard follows the present practice of designing on the basis of the temperature of the metal, as opposed to that of the steam. Temperature limitations on the use of electrically welded tubes of "rimming" steel are no longer included. Again following modern practice, the requirements for percentage elongations have been revised; they are related to an equivalent gauge length of four times the square root of the area of the test piece. And modifications have been made to the requirements for the expanding test on tube ends.

Copies of these standards may be obtained from the British Standards Institution, Sales Branch, 2 Park Street, W.1.

Observations on the Process of Nickel Deposition by Thermal Decomposition of Nickel Carbonyl at Low Pressures

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An account is given of observations made and experimental determinations carried out during the development of a method for the deposition of nickel by thermal decomposition of nickel carbonyl at low pressures. Details are given of the variables controlling the process and the properties of the coatings obtained, such as appearance, micro-structure, micro-hardness, ductility, etc. The adhesion and porosity of the coatings on various metallic bases are assessed and also such factors as the control of thickness applied and the distribution on various shapes. The role of variables such as temperature, pressure, rate of flow and composition of vapour are discussed and an attempt is made to relate these factors with each other and the properties of the coating.

(*Continued from page* 173 *of the April issue*)

IV.6.2. Micro-Structure

Study of the appearance of etched cross-sections of nickel coatings viewed at magnifications of between 200 and 400 diameters showed that they could be roughly classified into groups as follows :—

(*a*) Columnar, including conical and acicular or fibrous types (Figs. 16–18 (upper parts)).

(*b*) Dendritic or arboreal (Fig. 19).

(*c*) Banded, with or without visible grain pattern (Figs. 20–22).

(*d*) Very fine grain pattern with little visible direction of growth (Fig. 23).

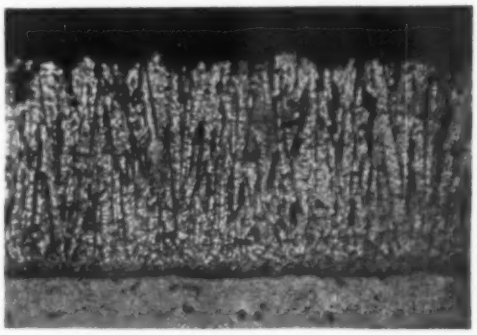

Fig. 16.—Columnar type of microstructure. Hardness 120 D.P.N. Etched 5% nital + 10% hydrogen peroxide (20 vol.). × 570

Generally, columnar structures of the large grain or conical variety were not frequently found ; the acicular or fibrous type bordering on dendritic was more often seen. Dendritic and fine grain structure was mostly predominant. Examples of an equi-axed type of structure were also obtained, such as that seen in Fig. 17 near the substrate (see below). The dendritic structure was most frequently found on prominent areas of a plated specimen where deposition rates were somewhat higher

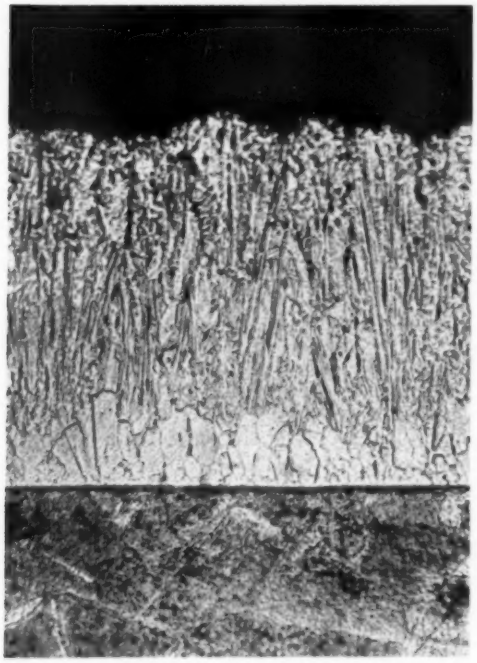

Fig. 17.—Mixed type of microstructure. Hardness 275 D.P.N. (columnar) and 160 D.P.N. (equi-axed). Etched 5% nital + 10% hydrogen peroxide (20 vol.). × 400

Fig. 18.—Mixed type of microstructure. Hardness of large grains 150 D.P.N. × 200

Fig. 19.—Dendritic type of microstructure. Hardness 150 D.P.N. Etched 5% nital + 10% hydrogen peroxide (20 vol.). × 200

than elsewhere, and also in coatings produced at low temperatures. Coatings with a banded type of structure were found when oxygen (as air) was introduced during plating (Fig. 21). The sharp bands seen in Fig. 20 were, however, produced by admitting oxygen in short bursts to the plating vessel. More diffuse types of banding were frequently seen in coatings where air had not been admitted (Fig. 22) and the effect cannot be attributed directly to any one factor, e.g., oxygen or carbon or etching effects.

On heat treatment, most coatings underwent recrystallisation to give an equi-axial type of grain. Examples of microstructures obtained by heat treatment carried out between 400° and 1,200° C. are shown in Figs. 24–28. Recrystallisation commenced below 400° C. (Fig. 24), and fairly considerable grain growth took place at 1,000° C. (Fig. 27).

Examination of the etched cross-section of a coating occasionally revealed abnormalities and defects, of which the following were typical :—voids both isolated (Fig. 29) and diffuse (or spongy) (Fig. 30) ; fan-like structures often associated with nodular coatings (Fig. 31) ; gaps or fissures between nodules (Fig. 31) ; loosely attached nodules (Fig. 31) ; lamination occurring in banded types of structures ; and loose grain boundaries resulting from heat treating some coatings. These defects would all adversely affect to a greater or lesser degree the physical properties of the coatings. Possibly by far the most serious type of structural defect was shown by the fissured dendritic type of growth (Fig. 32), since the gaps extending downward into the coating present obvious " stress raisers." This type of structure was produced by plating at low temperatures, i.e., 150° C., the effect becoming less pronounced and somewhat different in character as the temperature was increased to 200° C.

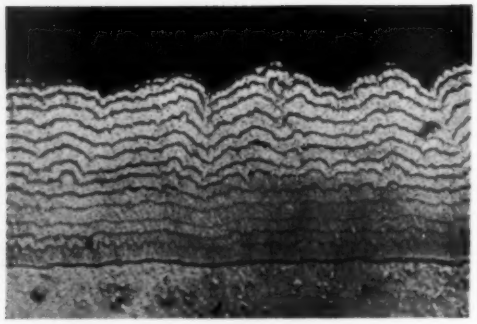

Fig. 20.—Banded type of microstructure obtained by admitting air during plating. Hardness 380 D.P.N. Unetched. × 270

IV.6.3. Hardness

Nickel coatings were obtained with hardness covering a wide range of values. Deposits produced from vapour to which a certain proportion of oxygen (as air) had been admitted were extremely hard. For example, a cross-section through the coating shown under magnification in Fig. 21 gave hardness values up to 850 D.P.N. The lowest hardness value obtained was 650 and was near the surface of the coating. At this stage of the plating the concentration of oxygen in the plating gas was the lowest, since it was reduced in stages as the plating proceeded.

In the lower range of hardness, coatings showed medium to large grains usually of the columnar type, as deposited, or equi-axed if heat treated. The range of hardness values here was approximately 100–200 D.P.N. Not all coatings with low hardness values had large grained structures, some with fine dendritic types of structure

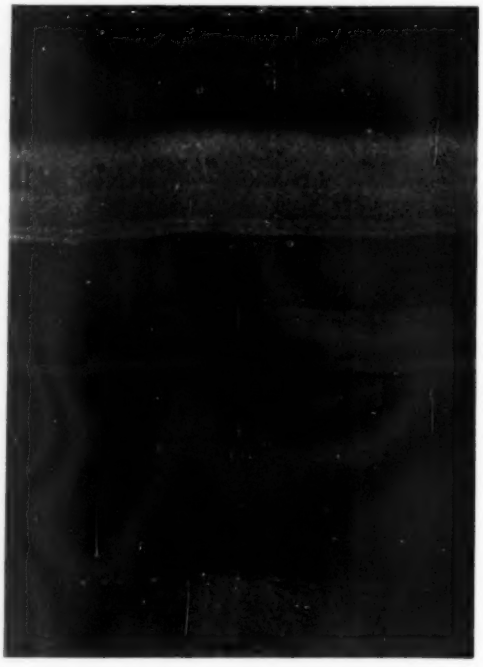

Fig. 21.—Banded type of microstructure obtained by admitting oxygen continuously during plating. Hardness 650–850 D.P.N. × 230

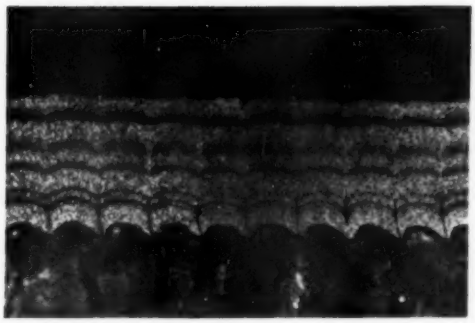

Fig. 22.—Diffuse bands arising from unknown causes. Note fissures caused by rough machining ; also smoothing action. Hardness 431 D.P.N. Etched 5% nital + 10% hydrogen peroxide (20 vol.). × 200

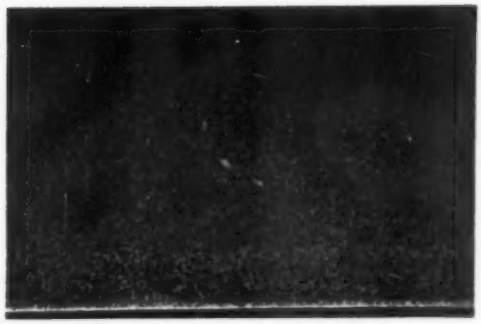

Fig. 23.—Fine grain pattern. Etched 50/50 nitric-acetic acid mixture. × 270

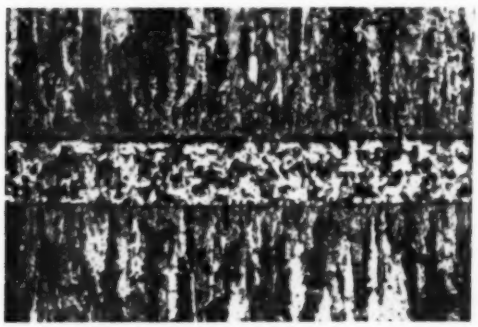

Fig. 24.—400° C. × 230

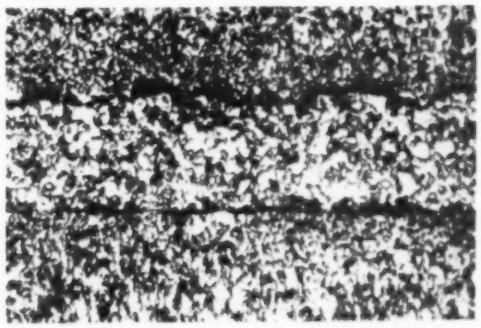

Fig. 25.—600° C. × 230

Figs. 24–28 show microstructures after heat treatment for 1 hour at various temperatures. Backed with electro-deposited nickel. Etched 5% nital + 10% hydrogen peroxide (20 vol.).

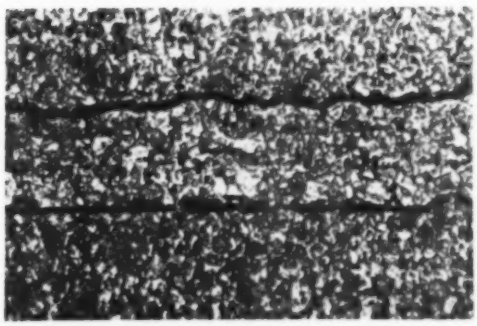

Fig. 26.—800° C. × 230

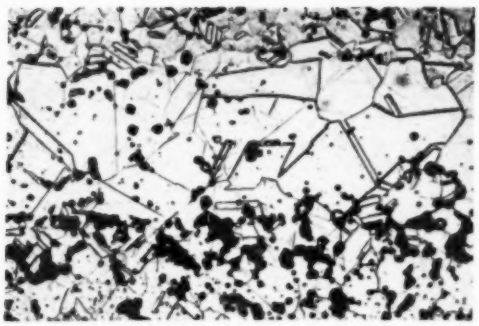

Fig. 27.—1,000° C. × 270

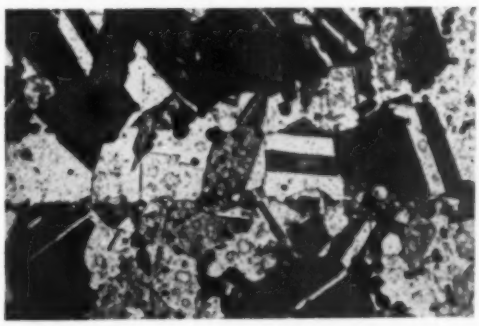

Fig. 28.—1,200° C. × 270

had low hardness values (Fig. 19) ; there was some doubt, however, whether the true hardness of these coatings was being measured, since fissures, gaps or sponginess were also often present, and hence a possible lack of support or cohesion from the body of material surrounding the impressions may have been responsible for the apparent low hardness. The fact that high hardness figures were sometimes obtained from coatings exhibiting this type of structure would seem to confirm this view. In the hardness range of 200–300 D.P.N. the structure exhibited by coatings varied, fine columnar, dendritic and fine grain structures being obtained. Fine grain structures without marked direction of growth predominated in the upper range, i.e. 250–300 D.P.N. At a hardness of 350 and above, the banded type of structures were mainly present.

IV.6.4. Ductility

Brittle coatings fractured on bending through considerably less than 90°, whilst the most ductile withstood a score or more bending cycles through 180°. Coatings produced by plating in the presence of oxygen were the most brittle, being scarcely able to withstand slight flexing. These coatings had fine structures, frequently banded, as shown in Fig. 21, and as already stated a high hardness value. Coatings of lower hardness values, i.e. less than 450 D.P.N., with banded types of structure were not so brittle. Coatings with only a few sharp bands, suggesting interruptions in plating, were not usually brittle. The most ductile coatings were generally those with medium to low hardness values showing medium size compact even grains. Ductility approaching that of commercial nickel foil was obtained in certain instances. The nickel film in its early stages of growth, i.e., before the matt stage, was usually of good ductility, but frequently became brittle following the appearance of the matt finish.

The coating with the dendritic type of structure, although often having low apparent hardness was usually quite brittle, values of less than 1½ bends being obtained, especially where extensive nodular growth or deep fissures of the type associated with low plating temperatures were present.

Annealing deposits at temperatures of 400° C. and upwards often resulted in an improvement in ductility where there were no defects such as nodular growth or fissures. Where recrystallisation within the coating gave rise to coarse or loose grain boundaries, improvement in ductility of the coating was not marked.

V. DISCUSSION

V.1. Published Work

The only publications giving detailed information on metal deposition by thermal decomposition of the carbonyl relate to the metals molybdenum,[3] tungsten,[3] and chromium.[4] The carbonyls of these metals differ considerably in properties from those of nickel carbonyl, and as a result the conditions of depositions and techniques employed vary considerably from those employed here.

The results given therefore cannot be compared at all closely with those obtained in this work. Similarities, however, exist, in that powdery decomposition of the vapour takes place remote from the specimen under certain conditions, co-deposition of carbon occurs, and oxygen has an embrittling effect on the deposits. Temperatures employed for deposition of molybdenum, tungsten and chromium were generally much higher and pressures much lower. Rates of flow of vapour in grammes per hour were not directly measured, but were apparently very much lower than employed in this work ; also the vapour was usually considerably diluted with hydrogen. Embrittlement of the coatings due to carbides resulting from co-deposition of carbon was not apparent in nickel deposition from the carbonyl. The extent to which sound, ductile films of these metals were obtained cannot be readily ascertained.

V.2. Decomposition Process and Black Powder Formation

Nickel deposition from the pure undiluted carbonyl vapour represents one of the simplest situations for study in vapour deposition processes, since there are only two gaseous compounds to consider, i.e., nickel carbonyl and carbon monoxide.

According to Bawn,[8] nickel carbonyl decomposes both in the gaseous phase and at the walls of the reaction vessel, the proportion being about 4 to 1 initially, and somewhat lower when the nickel film exceeds a certain thickness. The conditions of these experiments differ somewhat from those employed for plating, but it would probably be safe to assume that during plating decomposition occurs predominantly in the gas phase. Much nickel is liberated in the gaseous phase, therefore, near the specimen walls, and is not directly deposited upon them. The property of the coating must depend largely upon the state in which the nickel arrives at the depositing surface, the best coatings probably being obtained where the nickel arrives in the " nascent " condition. Collisions of nickel atoms with one another before the depositing surface is encountered would occur under most conditions however, and thus a proportion of the nickel would probably arrive as associated atoms or particles. A coating thus formed would be inferior in properties, depending on the extent of particle inclusion, and would in more extreme conditions be more or less powdery or loosely coherent. Reducing the amount of particle formation might therefore result in coatings of improved properties. The reduction might not be readily achieved, but a low partial pressure of nickel carbonyl (Section V.4.) must clearly favour a low rate of collision of nickel atoms. Decomposition occurring within a relatively thin zone should also favour a low degree of association of the atoms, as compared with an extensive zone where the nickel arriving from the outer parts would have more opportunity of collisions. Thus, low pressures and high linear velocities would seem to be the conditions required to keep particle formation down to a minimum. Experimental determinations have not yet been carried out to check this view, but, from experience, coatings produced at pressures below 2–3 mm. have a better appearance than those at higher pressure (low linear velocity). Much lower pressures and higher velocities than hitherto used should show a clearer trend in results, but in practice pressures much lower than 1 mm. are unlikely to prove economical.

Black powder formation on the walls of the bell jar and in the vicinity of the specimen was a very common occurrence. It was first detected as a transparent brown stain on the walls of the bell jar near the specimen, and often within a few minutes had ceased to develop beyond a thin band or ring. This ring, which was black and ½ to 1 in. in width, varied in intensity, being semi-transparent in mild conditions and forming a thick crust in more severe conditions. Chemical analysis confirmed

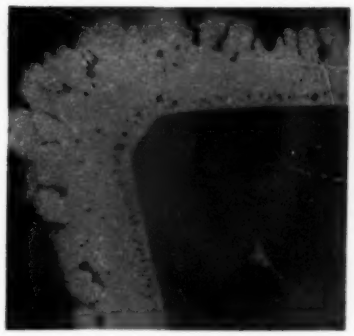

Fig. 29.—Nodules and voids. Unetched. × 125

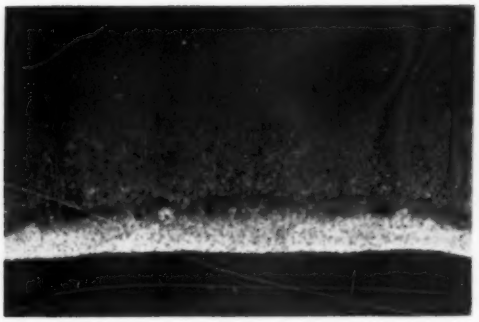

Fig. 30.—Spongy. Etched 50/50 nitric-acetic acid mixture. × 250

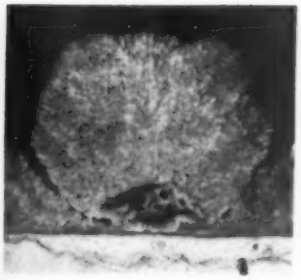

Fig. 31.—Large nodule. × 145

the black powder to be nickel with a certain proportion of nickel oxide. The most probable cause for the appearance of the black powder during plating was that decomposition in the vapour phase occurred beyond a certain distance from the specimen at which all the nickel liberated reached the specimen. The powder was carried by convection currents to nearby surfaces such as the bell jar walls and thermocouple stand, to which it adhered and accumulated to form a black powdery deposit. It has been suggested that the black powdery deposits form on the bell jar walls because the walls become sufficiently heated to initiate low temperature deposition. Black powdery coatings of similar appearance have been observed on metallic specimens at very low temperatures and these coatings resemble those described. When a deliberate attempt was made to produce black powder on the walls of the bell jar by heating the walls locally, a bright mirror was produced but no black powder. The appearance of black powder along the bore of the outlet pipe, swirl patterns in the upper parts of the bell jar, and black flakes in suspension in the bell jar at higher temperatures, all support the view that the powdery deposits originated from nickel liberated in the vapour phase.

No very convincing explanation can be suggested to account for the greater tendency for black powder formation to occur when employing large specimens in the large bell jar; most probably, however, as the extent of the decomposition zones surrounding the specimen increases with the specimen size there is a reduced probability for all the liberated nickel to reach the specimen.

Black powder formation during plating did not appear to result in any pronounced coating defects or coincide with any obvious deterioration of coating properties. The fact is not surprising since it is held that black powder forms as a result of vapour phase decomposition remote from the specimen; by implication, conditions nearer the specimen are but little changed.

However, whilst no obvious disadvantages appear to arise from plating at conditions where black powder forms in limited quantity (i.e. not sufficient to obscure the interior of the bell jar), it seems unlikely that the optimum conditions are achieved, since it infers that some nickel reaches the specimen from the maximum possible distance and has had the maximum opportunity to form particles (see above). However, with large objects in large plating chambers, or where large vapour flows, high deposition rates, high linear velocities of vapour (Section V.4.), etc., are employed, it may not be possible to avoid black powder formation, even with carbon monoxide additions. Reducing the temperature into the region where quality would suffer would not be justified unless the extent of black powder formation was prohibitive (see Section IV.1.1.).

V.3. Vapour Movement in the Bell Jar

Nickel carbonyl vapour enters the bell jar from the top or the bottom, depending upon whether the flow rate is downward or upward, and undecomposed vapour together with carbon monoxide from decomposition of the carbonyl leave the bell jar at the opposite end. Carbon monoxide is generated at or near the specimen and, being hot and considerably less dense than nickel carbonyl vapour, rises to the top of the bell jar. Nickel carbonyl vapour entering the bell jar from the bottom would not

Fig. 32.—Fissured structure obtained with plating at low temperatures. Hardness 150 D.P.N. × 630

rise rapidly on account of its high density, but would flow steadily upwards and mix only slightly with the carbon monoxide present before reaching the specimen. On the other hand, vapour entering from the top of the bell jar would descend with the assistance of gravity through hot streams of carbon monoxide rising from the specimen. Dilution and heating of the vapour would thus occur before reaching the specimen to a considerably greater extent with downward flow than with upward flow. On account of the high vapour density of the carbonyl vapour, vapour escaping decomposition on the downward path would tend to accumulate at the lower part of the plating vessel. Thus, during plating, whether the flow were upward or downward, there would tend to be a high concentration of carbonyl vapour in the lower part of the plating vessel and a high concentration of carbon monoxide in the upper part.

Observation of gas movement in the bell jar during plating has been confined to those occasions when conditions of plating were such as to cause black flakes to form in the bell jar. These black flakes were swirled around in the bell jar by the combined effects of gas flow and convection, and it was apparent that velocities were considerably in excess of the calculated linear velocity, even assuming all carbonyl to be decomposed to carbon monoxide (i.e. about four times the volume of vapour employed). Moreover, some of the flakes were moving in a direction opposite to the gas stream. Most of the movement took place above the specimen and obviously was connected mainly with convection streams. Under these conditions, it seems likely that some of the vapour which escapes decomposition is recirculated. Where the linear velocity of vapour (Section V.4.) is sufficiently high, recirculation will not occur.

Initially, plating takes place from pure nickel carbonyl vapour. Carbon monoxide is immediately formed which, although removed extremely rapidly by oncoming vapour, convection, and diffusion processes, would nevertheless have the effect of slowing down the rate of decomposition of vapour. As soon as the carbon monoxide layer surrounding the specimen diminished, the rate of plating would increase, since more vapour would be able to approach the specimen walls by diffusion and turbulence. Carbon monoxide would tend to build up again and the process continue until a balance was established between the rate at which carbon monoxide was removed and that at which carbonyl vapour arrived. It is possible that such a process could take place with an element of periodicity in which the carbon monoxide and carbonyl vapour content fluctuated within certain limits in a regular manner with time.

Although gases would be moving rapidly through the zone surrounding the specimen in which decomposition was occuring, the size and shape of the zone would presumably be fairly stable. A change in plating conditions would, however, alter the shape and size of the zone, as for example when the gas velocity was increased or the temperature lowered, when the zone could be expected to diminish. Pressure would probably not have much effect, but a change in direction of vapour flow would probably alter the shape of the zone.

Obviously much could be learnt about vapour movements in the bell jar from experiments carried out employing some form of tracer technique.

V.4. Temperature, Pressure, Rate of Flow, etc.

No appreciable amount of deposition can take place without raising the temperature of the object to be coated. The other variables, therefore, can only influence the process when the temperature is high enough to permit deposition. The importance of temperature is therefore readily appreciated ; indeed it might be said that the success of the process developed depends to a large extent on the ease with which nickel carbonyl vapour, relatively stable at ordinary temperatures, is almost completely decomposed with only a very moderate elevation of temperature. Vapour can thus be conducted without appreciable decomposition sufficiently near to the specimen to allow almost all the nickel liberated to be included in the coating. Some vapour deposition processes require temperatures higher by a factor of two or three, which excludes from treatment metals with low melting points and favours the formation of brittle diffusion zones at the interface ; the effects of differential thermal expansion are also more troublesome.

Up to 200° C. the specimen temperature influences the appearance, properties, and structure of the coating to a greater degree than any other factor except the introduction of oxygen ; coatings tend to be dark in colour, velvety in texture, and have a fissured dendritic microstructure. This type of structure might result from reduced mobility of the nickel atoms at a lower temperature, and the consequent tendency for deposition to continue on existing centres rather than from fresh nuclei. Growth tending to take place in the direction of the arriving atoms (or particles) rather than parallel to the substrate would also be anticipated, i.e., outward growth[9] would thus be favoured. The structure and texture of coatings produced at 150° C. seem typical of this type of growth.

No proper assessment has yet been carried out to show the effect of increasing temperature on ductility and hardness. Results of random observations show lack of consistency, but on the whole suggest that properties do not change a great deal above a temperature of 230° C. ; below 200° C., however, there is a quite definite progressive deterioration. A temperature of 210° C. might be regarded as a safe minimum, whilst the maximum might be regarded as just below that at which black powder begins to form (see Section V.2.). The upper limit of temperature could undoubtedly be extended considerably by introducing means to localise the effects of convection and radiation. Results of such experiments may lead to practical advancements as well as factual data.

The pressure recorded in the bell jar during plating represents the sum of the partial pressures of nickel carbonyl vapour and carbon monoxide released by decomposition of the vapour. In this work it has been the practice to control and measure only the total pressure. The partial pressures of nickel carbonyl vapour and carbon monoxide are in general controlled by the rate of flow of vapour and decomposition efficiency. Other factors, however, have to be considered when studying this variable. A small gradient in total pressure obviously exists in the direction of vapour flow, but the partial pressure of nickel carbonyl would have a very much steeper gradient, since at the point of entry of vapour it would equal the total pressure, and at the outlet be somewhere between half the total pressure (assuming 50% efficiency as minimum) and zero (at 100% decomposition efficiency, assuming no recirculation). At the surface of the specimen the partial pressure of carbonyl vapour would also be low, however, probably as low as, or lower generally than, at the point of exit from the bell

jar. Changes in partial pressure of carbonyl vapour in the bell jar would then only be reflected by corresponding small changes in partial pressure at the surface of the plating specimen.

Variation in the total pressure was normally effected by control of the pumping speed. The mass velocity of vapour is thereby maintained constant, and the partial pressures of carbonyl vapour and carbon monoxide increase more or less in the same proportion to one another, i.e. $p\frac{(100-f)}{100}$ to $4pf/100$ where p is the partial pressure of nickel carbonyl and f is the percentage efficiency of decomposition. Special measures have to be taken to keep the linear velocity of vapour constant (see below); efficiency is normally not sensitive to pressure changes. Variation of the total pressure can also be effected by varying the rate of flow of the nickel carbonyl (maintaining constant linear velocity). Thus, increasing the pressure in this manner involves increasing the rate of plating and results in a lower efficiency of decomposition. The partial pressure of nickel carbonyl vapour would thereby be increased in greater proportion to that of carbon monoxide. Total plating pressure may also be increased by introducing carbon monoxide (or other gas) from a separate source. It would thus be possible to study the effect of pressure at constant partial pressure of nickel carbonyl vapour, or the effect of dilution of nickel carbonyl vapour with carbon monoxide (see Section V.5.). With modifications to the equipment the pressure range of study might be extended up to atmospheric pressure and above.

Since the rate of flow of vapour determines the rate of deposition, it is important to know to what extent variation of rate of flow is accompanied by other effects. Within the restricted range of 0·5–1·5 g. nickel per hour, the only effect observed has been a slight increase in tendency for black powder formation. At higher flow rates coatings appeared somewhat less satisfactory, but no clear evidence in terms of bend tests, micro-hardness and microstructure have yet been obtained to show that the coatings are inferior as regards mechanical properties. What few results have been obtained are somewhat conflicting, but show that coatings with good mechanical properties are possible at high rates of flow. At a rate of flow of 10 g. of nickel per hour (efficiency 46%), the rate of deposition with downward flow on 1 in. diameter cylinders approached 20×10^{-3} in. per hour, which is exceedingly fast when compared with rate of deposition normally achieved by electrodeposition. At 1 g. of nickel per hour the deposition rate was 3×10^{-3} in. per hour. Limitation to the maximum flow rate appears to be set by the design of equipment, black powder formation, and efficiency considerations. It will be apparent, however, that these results refer to a particular set of conditions and do not apply for example to larger specimens requiring large bell jars, where plating rates of 3×10^{-3} in. per hour could not be achieved without severe black powder formation. At the 10 g. per hour flow rate in the small bell, blackening of the bell was fairly severe, the specimen rapidly being obscured from view, but the appearance of black flakes, which is regarded as prohibitive, was not observed at the plating temperature employed (200° C.).

Little has been said about the effect of linear velocity of vapour. It is a variable which cannot be conveniently measured or controlled directly, but should not for this reason escape attention; indeed, it may well be a more important variable than total pressure. From experience, high linear velocities appear to favour the production of coatings of good appearance, although a certain amount of black powder formation, particularly at higher pressures, takes place. On the other hand, low linear velocities at high pressures appear to favour fissure development.

In studying the effect of linear velocity variation on the properties of the coating, special means will need to be introduced to keep the pressure constant or vice versa. One method of achieving this would be to conduct the vapour down one of a series of delivery tubes within the bell jar onto a cylindrical specimen of the same diameter as the tube. By repeating the experiment with a delivery tube and specimen of different diameter, variation in linear velocity will have been achieved at the same pressure. Alternatively, by varying the pumping speed the pressure can be varied and the linear velocity held constant by employing a delivery tube of the appropriate cross-section.

(*to be continued*)

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Choosing Copper Tube Thickness

THE Copper Development Association issued last year a publication entitled "The Strength of Copper Tubes and Cylinders" to meet the demand for information, by users of copper tubes and cylinders, and for guidance concerning the effects of operating conditions on design principles. In the Introduction to this booklet there appears the following statement:—

> "The thickness of copper tubes and cylinders have been and still are sometimes chosen in a rather haphazard manner depending mainly on usage and ready obtainability."

In a recent booklet issued by the Associated Builders' Merchants, Ltd., entitled "Hot—Cold," this statement has been misquoted on page 14 as follows:—

> "The above would seem to justify the recent comments by the Copper Development Association wherein they refer to the Standards for copper tubes and cylinders as being haphazard and wasteful."

The Copper Development Association wishes to dissociate itself emphatically from the statement made in this pamphlet of the Associated Builders' Merchants Ltd., since no reference was made to British Standards in the Introduction from which the passage was misquoted, nor does the statement in any way represent the views of the Association.

Exterior view of new pilot plant block.

United Steel's New Pilot Plant Laboratory Block

Equipment for Fuel and Furnace Research

A LARGE, self-contained building for pilot plant studies has been completed recently and is now in operation at the Swinden Laboratories, Rotherham, of The United Steel Cos., Ltd. At present, it is primarily engaged on fuel and furnace research, and three combustion rigs have been constructed, consisting of a flame tunnel, and scale models of an open hearth furnace and a pusher type reheating furnace.

When the laboratories were built in 1952, there were four main blocks, one of which was divided into a machine shop and development bay, where tests could be made on relatively large scale equipment. During the last few years, almost all the space in this bay has been absorbed by permanent equipment, notably three induction melting furnaces, a vacuum melting furnace, a rolling mill, and a number of furnaces used for specialised tests on refractories. To provide space for pilot plant work on a substantial scale, therefore, it was decided to build the new fifth block.

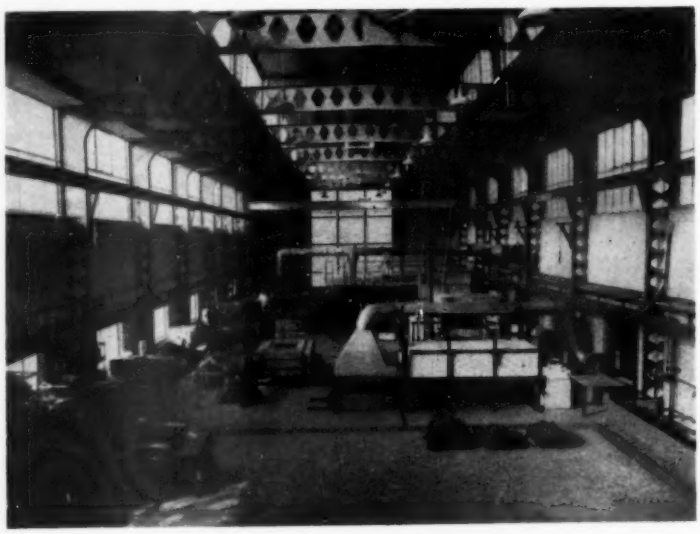
Purpose of Research

Over the last decade, a great deal of pioneering work has been done at Swinden Laboratories on the aerodynamic aspects of furnace design. This has provided a background of science in relation to which new designs can be considered, but like all research it has raised new questions, the answers to which can only be obtained by further study.

Fairly detailed information is now available on flow pattern and mixing in many types of furnace, but research at operating temperature has for the most part been limited to work on full-scale open hearth and reheating furnaces, and co-operative tests in the International Flame Research tunnel in Holland. Most of the urgent questions demand the precise measurement of heat transfer which, if made on actual furnaces, would involve a vast expenditure of both time and money. By making possible the testing of one-fifth scale furnaces at full operating temperatures, the new laboratory should not only enable such information to be obtained at a fraction of the cost, but with a far closer control of such variables as fuel rate, air supply and thermal loading.

Laboratory Services

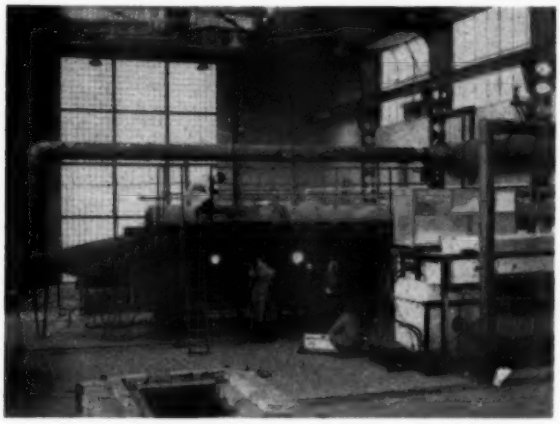
The new laboratory, which is now operational, provides four " stations " for major pilot rigs and additional areas for other work. Service pipes for gas, water, oil and steam, are installed in an under-floor walkway



General view of interior of pilot plant block with one-fifth scale model of continuous pusher type reheating furnace in the foreground.

tunnel running along one side of the building. Floor trenches across the bay permit distribution to individual rigs without obstruction. Electric power is available from a continuous bus-bar trunking system running along the side wall with tap-off points at 2 ft. intervals. Other services, e.g. hot air, compressed air and circulating water, are located on the opposite wall, with tappings at convenient points.

Opposite each of the "stations" is an opening in the wall, covered with sliding doors, and leading into a courtyard enclosed by a 10 ft. high wall of novel construction, lined on the inside with hollow concrete blocks. This is designed to minimise noise from the combustion rig exhaust, which will normally pass through the door openings. On dismantling a rig, the



47 ft. long flame tunnel in operation, with open hearth furnace model on right.

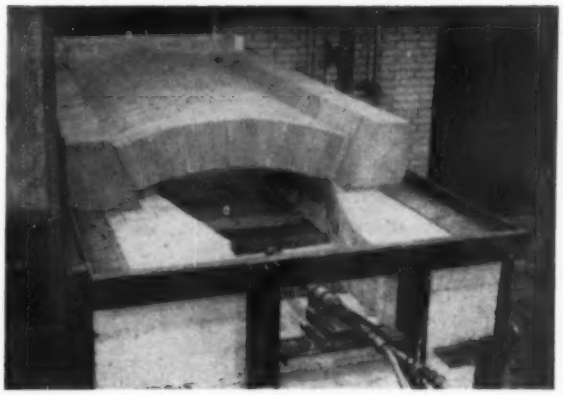
station can be readily cleared of all temporary service piping.

Building and Equipment

The building is of steel portal frame construction and comprises a main bay serviced by a two-ton crane, a ground floor laboratory, three first floor offices, an entrance with toilet facilities, a basement for the central heating boiler, an air compressor basement, and an open yard. The principal dimensions are :

Main bay : length 135 ft., width 47 ft., and height 26ft.
Main floor area : 6,300 sq. ft.
Ground floor laboratory area : 600 sq. ft.
Amenities and office area : 1,000 sq. ft.

Fuel oil is stored in three external tanks, each of 2,500 gallons capacity and individually sufficient for a day's operation at the maximum anticipated load of 100 gal. hr. The oil is pumped to the rigs through pipelines in the under-floor duct system, final temperature control being by means of individual electric line heaters. Town's gas is also available, though in more limited supply. To enable actual furnace conditions to be simulated more closely, hot air is provided at a temperature of up to 700° C. from an oil-fired air heater of 150,000 cu. ft. (N.T.P.)/hr. capacity. The oil can be atomised by means of compressed air or steam, the former being supplied from three compressors, which are installed in a basement chamber to reduce noise. Each of these supplies air to its own receiver at 150 lb./sq. in.



Close-up of open hearth furnace model, showing the calorimeter hearth.

and at a maximum rate of 84 cu. ft./min. of free air. The receivers can also be coupled together and one, two or three compressors used as required.

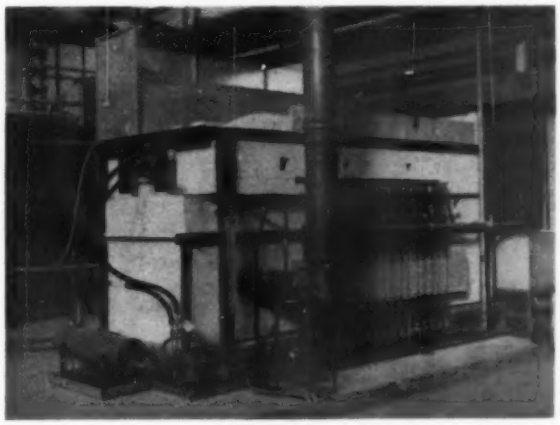
Steam is supplied from a fully automatic oil-fired boiler of 1,250 lb./hr. capacity at 250 lb./sq. in. pressure. This is fitted with a superheater, capable of giving steam at up to 200° F. superheat, which can be bypassed if saturated steam is required. Circulating water for cooling purposes is available at a rate of up to 6,000 gal./hr., a closed circuit system with an air blast water cooler being installed in the adjacent courtyard.

Combustion Rigs

Three units have already been constructed ; brief particulars of which are given here :

Flame Tunnel.—This is a cylindrical brick-lined tunnel, 47 ft. in length, with a 20 ft. test section of 6 ft. internal diameter. It will be highly instrumented and will be used primarily for flame evaluation, to answer such questions as the effect on heat transfer of changing from steam atomisation of oil to air atomisation, and whether flame properties are influenced by atomisation at the base or tip of the burner.

Model Open Hearth Furnace.—This is a one-fifth



One-fifth scale model of a 100-ton, cold charged, open hearth furnace.

scale model of a 100-ton cold charged furnace, and will be used to test the effect of such variables as vertical burner angle. It is equipped with a calorimeter hearth and should enable the contributions to heat transfer by radiation and convection to be separated.

Continuous Pusher Type Reheating Furnace.—This is a one-fifth scale model of a pusher type furnace as used in bar mills. It will be fed automatically with 2 in. square billets which, after quenching, will return to the incoming end in order to maintain a continuous load. The furnace will be fully instrumented and will be used initially to evaluate the effect of certain principal variables, e.g. roof height and shape, on heat transfer.

Although substantial, these initial rigs are not considered permanent, and will in due course give way to others, such as those required for the study of heat transfer in regenerator systems. A major question which it is hoped can be answered by the use of unconventional designs is the desirability or otherwise of recirculation in open hearth furnaces.

The activities of the laboratory will not be limited to combustion; in fact, the first tests made were in connection with the development of certain specialised engineering equipment.

Sheet Iron Enamels

THE last ten years or so have seen considerable reductions in coating thicknesses in the vitreous enamelling industry, due largely to the introduction of titania self-opacified enamels. However, in the last five years the situation has remained static, and the industry still faces a problem of over-thick coatings—either general or localized—giving rise to chipping and shaling failures. Two factors are mainly resposible for this: in the first place, enamel frits technically able to reduce the coating thickness were not available; and secondly, the enameller is faced, in a proportion of his production at least, with either applying successive coatings to obtain a good quality finish or suffering very high scrap losses.

A requirement therefore exists for sheet iron enamels capable of very thin application and giving a maximum of good quality work with no more than two coatings. The obvious solution to the physical reduction in thickness is to eliminate the ground coat entirely from the process, but this is not yet practicable, and until it is the approach should be to reduce the ground coat thickness to the minimum consistent with good enamelling results. Ground coats do not possess the mechanical strength of titania self-opacified cover coats, and their vulnerability in this respect increases markedly with thickness. It follows, then, that the thinnest possible film of ground coat should be aimed at if the toughest and most durable coating is to be obtained.

Ground coats have now been formulated to provide the necessary technical performance at thicknesses of the order 0·002–0·003 in., against the normal 0·004–0·005 in. Production experience with these enamels shows them to have a remarkable degree of heat resistance in the thickness range indicated; coating breakdown with successive fusings is not a hazard. A reduced tendency to beading or blobbing on edges and corners—a potent source of enamel failure—is obtained, and a good quality cover coat finish results without the marked "orange-peel" effect found on many pieces fused in a vertical plane. A saving in materials from 25 to 40% can be achieved by thin application enamels.

Recent improvements made by Metal Porcelains, Ltd., of Smethwick, in titania self-opacified cover coat enamels have been concentrated on two important physical characteristics: raising appreciably the coefficient of expansion; and lowering the softening point, giving greater fluidity at enamelling temperatures. These enamels contribute to thinner, tougher coatings in two respects. First of all, their workability is improved, reducing boil and blister in first coat work and reducing defects due to thermal stresses—for example "strain-lining" is largely eliminated. Thus, a higher proportion of one cover coat work is obtained, particularly on components having a lot of welded area, and on deep drawn pressings. These would include refrigerator linings, sinks, washbowls and all heavy flanged pressings. Further, the tendency to distortion during fusing on all flat panels is reduced, and chipping or shaling from raw edges, sharp radii and open beads is minimised.

Coil Annealing Furnace Contract

A SIX-FIGURE contract has recently been placed with Birlec, Ltd., by the Whitehead Iron & Steel Co., Ltd., Newport, Monmouthshire. Birlec is to design and build a heavy duty continuous driven roller hearth furnace for annealing steel strip in coil. The largest coil to be handled will have dimensions of 4 ft. diameter × 2 ft. high and weigh approximately 4 tons. The coils will be carried through the furnace on heat resisting alloy pallets.

The furnace will comprise essentially a loading table, inlet lock chamber, brick-lined inlet tunnel, heating chamber, brick-lined retarded cooling chamber, water jacketed cooling chamber, outlet lock chamber and unloading table. The furnace heating chamber, rated in total at 1,200 kW., is to be divided into a number of zones, each with automatic temperature control. A maximum output of five tons per hour is envisaged.

Material will be handled mechanically throughout the treatment sequence so that labour requirements will be at a minimum. There will be immediate visual indication of each mechanical operation, so that any fault developing can be rapidly detected. To meet the very stringent requirements as to surface finish of the work, controlled atmosphere of special purity will be provided from a generator of novel design.

Translations Index Cards

DUPLICATED cards, covering references to translations issued by the British Iron and Steel Industry Translation Service, and those listed in "Other People's Translations" (B.I.S.I.T.S.) are now available at 3d. each, plus postage, from The Madonna Press, 32a, Aboyne Drive, London, S.W.20. Additional copies of the same card are provided at 1d. each. The details include the B.I.S.I.T.S. or other reference number, the authors, the title, and the literature reference.

Unusual Fracturing of Hard-Drawn High-Conductivity Copper Strand

By Clement Blazey*

A description is presented of the fracturing of stranded copper conductor in the interval between lagging the drums at the completion of stranding and opening them for use. The phenomenon was associated with a change in the type of wood used for the drums and the author reports the results of an investigation into the cause of failure.

IT has long been known that wire, strand, and cable used in the electrical industry sometimes fail through being subjected to cyclic stress in service. Examples are lead sheathing on power and telephone cable; bare overhead conductors made of copper and cadmium-copper, as in telephone lines; and steel-cored aluminium strand, as in power lines. The present paper describes the fracturing of stranded conductor *in situ* on wooden drums in the interval of time between lagging the drums at the completion of stranding at the works and opening them for inspection at customers' depôts, or during the erection of the strand in the field. The instances of this unusual kind of failure (unique, so far as the author is aware) occurred in bare, hard-drawn, high-conductivity copper strand made by Metal Manufactures, Ltd., Port Kembla, N.S.W., and wound on wooden drums of the usual shape for use in power distribution in various parts of Australia.

Corrosion Caused by Timber

Until the early 'forties, the timber used by Metal Manufactures, Ltd., for making drums was principally hemlock imported from the west coast of N. America. It, or similar timber, had been used since the commencement of manufacture of copper strand in Australia in 1919 without any deleterious effect on the wire. At the outbreak of war with Japan in late 1941, imports of timber from America ceased, and the Company had perforce to use native hardwood such as eucalyptus pilularis, eucalyptus longifolia, and eucalyptus maculata, especially the last named, known as spotted gum. It was found that unseasoned hardwood could have a corrosive effect on copper and, in course of time, a number of complaints were lodged by customers about strand arriving at their depôts discoloured or corroded.

Nothing that was tried in the way of spraying the newly-made drums with bitumastic liquids, or lining them with waterproof paper, was effective in preventing corrosion. Rate of supply of timber to the works and high demand for strand made regular seasoning of the timber impracticable. The most effective solution to the problem was to dry the drums in the open air for as long as possible before using them at the stranders. The disadvantages of sawing, dressing, and nailing dry hardwood are well-known.

Corrosion and Fracturing

Until 1945, not one complaint had been lodged about strand having been received in both a corroded and fractured condition, but from late 1945 until 1953 there were about a dozen complaints of this nature. This strand varied in size from 7/0·064 in. to 19/0·083 in., most instances being 19/0·083 in., no doubt because it was the size most commonly in demand at the time. The dimensions of a drum for holding 19/0·083 in. strand are given in Fig. 1. Over the whole period, fewer than twenty drums contained fractured strand, which was a very small percentage of the total number made. Usually, affected strand had been left on drums unopened for several months, but in one instance the interval between manufacture and opening was as short as one month. In not one instance was fractured wire found in strand held at the works; all failures were discovered after delivery to users, but it must be added that drums of strand were rarely opened at the works after they had been lagged. Mode of delivery varied and could involve rail transport for several hundred miles, road transport for various distances, or combined rail, road, and ship transport for several hundred miles. There were no changes in mode of transport to account for fracturing. When softwood was again available, both corrosion and fracturing completely disappeared.

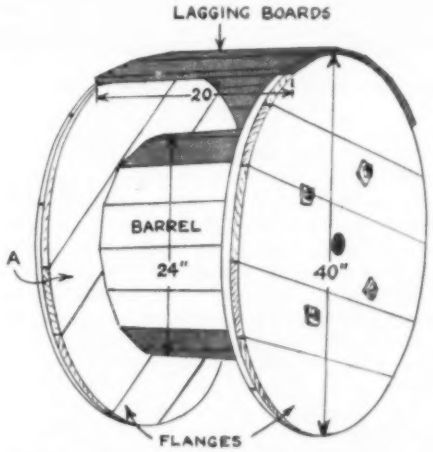


Fig. 1.—Dimensions of a wooden drum made to hold 2,150 yd. (2,656 lb.) of 19/0·083 in. copper strand. (The shading of certain boards serves merely to clarify the sketch: it has no other significance).

Corrosion was largely greenish and was most severe on turns or loops of strand in contact with and adjacent to the flanges of a drum. It was local in extent, and by

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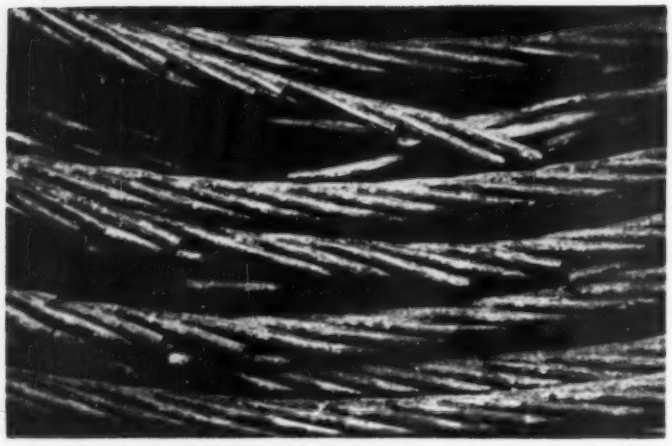


Fig. 2.—Corroded and fractured wires on a drum of 7/0·080 in. copper strand

far the greater part of the strand on a drum (2,150 yd. of 19/0·083 in. to 3,650 yd. of 7/0·064 in.) when opened for use was as bright as when it was manufactured.

Fractured wires were also restricted to turns of strand at or near flanges, and were not necessarily present where corrosion was most severe. The worst example is shown in Fig. 2. In this instance the flanges were removed from the drum after it had been returned to the works, months after manufacture, so that a photograph could be taken of the wires *in situ*. Scores of fractures were present where the strand was in contact with or adjacent to a particular board used in the construction of the inner layer of the flange (Board A in Fig. 1). This relationship between fracturing and a particular board (not, however, always board A) was found to apply to other drums. Fractured strand was invariably covered with a blue-black and not a greenish corrosion product, but many drums containing blue-black wire did not contain fractured wires.

Description of Fractures

Without exception, fractures were situated on the convex or tension side of the turns of strand, and were at right angles to both the surface and the longitudinal axis of the wires. As a rule, there were a number of complete or partial fractures in line along a short length of strand, as in Fig. 3, and occasionally a wire was partly fractured at two places within 0·5 in. of each other. In general, fracturing was repeated where the strand came a full revolution around the barrel of the drum into the vicinity of the board associated with fracturing, but it ceased to re-appear on turns more than several inches in from the board. Partial fractures were common, as was proved by flexing affected strand by hand. Fractures did not necessarily start at small surface folds, dents, scores, or concentrations of 'set surface' cuprous oxide inclusions within a wire.

A fractured surface, both as discovered by customers and found by hand flexing, consisted of two clearly defined regions, one, coloured blue-black, marking the extension of a crack originating at the surface in tension, and the other, a bright copper colour, marking the portion of the cross section that failed suddenly when it could not support the stress on the partly broken wire. (Fig. 4). The dark portion was always characterised by lines radiating from the point where the crack commenced and, in some instances, by less clearly defined arcs concentric to this point. The ratio of discoloured to clean portions varied from less than 10% in wires broken by hand to more than 90% in wires that, presumably, were the first to break in place on the drums. There was no reduction of area or 'necking' at fracture.

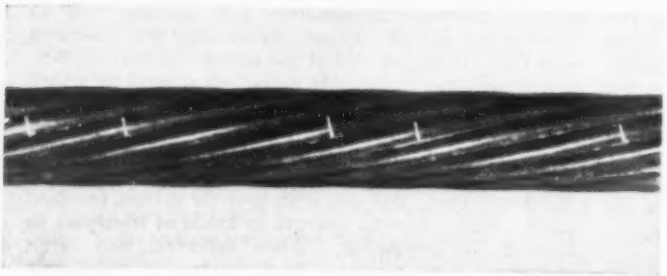
Spectrographic analysis, mechanical tests (tensile strength, percentage elongation, bends, twists in a 3 in. length, and wraps on and off), and measurements of electrical resistance were made on many wires taken from affected drums. They disclosed nothing abnormal to account for fracturing.

There was no record of any abnormal happening in manufacture of strand during the period associated with fracturing, such as the use of a particular brand of copper wirebar, a particular stranding machine, or peculiarity of weather or storage conditions.

The blue-black layer present on fractured wires was found by X-ray diffraction examination to be cuprous oxide with small amounts of cupric oxide. The greenish corrosion product was copper acetate.

Microstructure

In microsections of fractured wires, the oxide layer was seen to be composed of an inner and an outer



(Courtesy of the New South Wales Department of Railways, Electrical Branch.)

Fig. 3.—Incipient fractures in outer wires of 19/0·083 in. copper strand. The fine cracks have been marked with white paint to reveal their position on the blue-black strand.

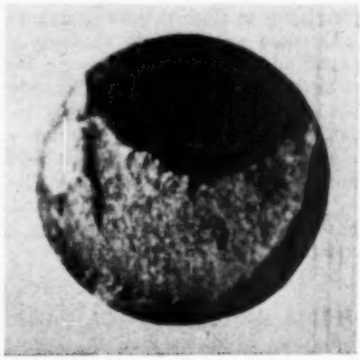


Fig. 4.—Wire fracture surface. × 20

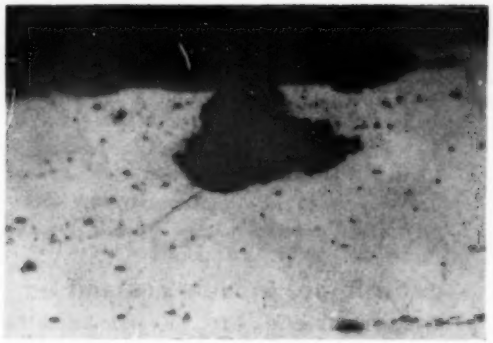


Fig. 5.—Longitudinal median section through a 0·083 in. wire, partly etched to show oxide (corrosion product) extending into the copper from the surface. ×500

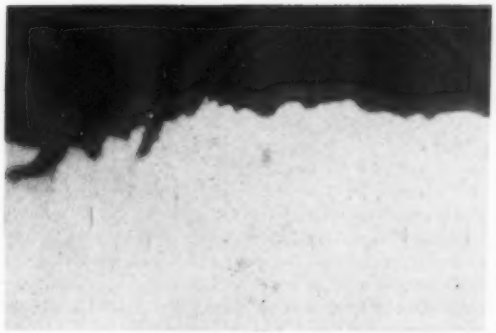


Fig. 6.—Longitudinal median section through a 0·083 in. wire showing thin lining of oxide (corrosion product) on an open fracture. Etched by polish attack with ammonia. ×1000

portion of slightly different tint, but mostly it was a uniform blue-grey not unlike the cuprous oxide particles normally present in oxygen-bearing high-conductivity copper, but lacking the pink tinge of cuprous oxide as well as the property of turning red in plane polarised light. At irregular intervals, especially on the side of the wire that was in tension on a drum, the oxide extended more deeply into the copper in rounded masses. Surface pitting in the usual sense of the term was absent.

Fig. 5 is a longitudinal median section through a wire showing oxide extending into the copper from the surface. Some sections showed intrusions of this nature at, or close to, the point where fracture started. Fig. 6 shows the thin lining of oxide on a fractured surface. Fig. 7 is another view of the same section a little distance from the open fracture, showing the tip of a crack that has penetrated half way through the wire, apparently following a transcrystalline path. In all sections of fractured wires, the oxide was present on the surface, on the weathered or discoloured portions of open fractures, and on both sides of incipient fractures.

Corrosion and Stress Experiments

Many experiments were carried out with different boards in the condition as received from the timber suppliers. Specimens were pressed against clean copper sheets and left for days in still air. Some corrosion was present on all sheets at the finish of the experiments, varying from slight tarnish through blue-black to bright green, but on no sheet was there a sign of deep pitting or cracking. Samples of boards that had a strongly corrosive effect in these experiments, as well as of boards that had been in contact with fractured wires on drums returned by customers, were submitted to three different government timber laboratories. They agreed that the boards were either spotted gum (eucalyptus maculata) or blackbutt (eucalyptus pilularis) and that the corrosive agent was almost certainly the vapour of acetic acid, but they were unable to say why a particular board and not others should be associated with fracturing. Experiments carried out at the works proved that the corrosivity of a board could not be determined by its apparent 'greenness.' The only certain test of corrosivity was actual trial in contact with copper.

Clean copper wire and strand were exposed to the vapour of acetic, formic, and butyric acids, ammonia, weak mineral acids, and freshly-made sawdust from various types of hardwood. The samples were taken from current production of wire and strand at the works, as well as from bright uncorroded portions of strand from drums on which corrosion and fracturing had been found after delivery to customers. They were bent into loops with as little permanent distortion as possible and exposed to vapour from the required liquid in glass jars for periods of hours up to months. One method of stressing the wire was to wind a length around a wooden cone so as to vary continuously the radius of flexure before suspending the assembly in a jar.

Although the copper became severely corroded in many of these experiments, especially in moist acetic acid and ammonia, not a sign of cracking appeared. A blue-black layer was developed in the earlier stages of exposure to some mixtures of acetic acid, water vapour and air, and on longer exposure this layer turned to green copper acetate. Suitable conditions were to suspend wire or strand in a jar containing 1 volume of 1% acetic acid in water to 10 volumes of still air—conditions which appeared to resemble those present within a lagged hardwood drum containing one or more boards of the necessary degree of greenness. But, since no cracking developed, it did not seem likely that static stress, leading to failure by stress-corrosion, was the cause of cracking in service.

High-purity copper is said to be immune from am-

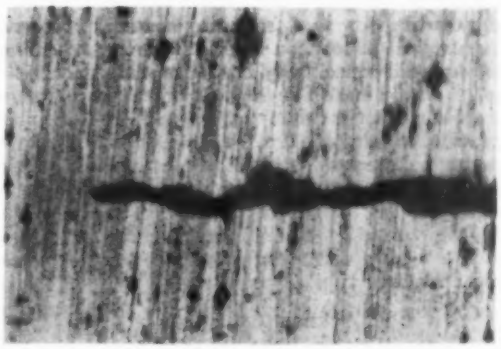


Fig. 7.—Longitudinal median section through a 0·083 in. wire showing tip of crack extending into the copper. The crack is lined with oxide (corrosion product). ×500

monia and mercurous nitrate stress-cracking, and tough-pitch high-conductivity copper is regarded as being free from liability to failure by stress-cracking or stress-corrosion cracking in service.[1]

Many attempts were made to combine corrosion with cyclic stress, using a machine of the type described by Kenyon.[2] A sample of wire 20 in. long was attached by means of a chuck to the spindle of a motor and bent to an arc by means of two inclined guides. The arced wire was then rotated on its longitudinal axis at 3,000 r.p.m. By varying the radius of arc, fatigue fractures could be developed in a desired time, but it was found difficult to control corrosion on a wire rotating in this way, as the rotation affected the adherence of corrosion products in a moist environment. The method also suffered from the tendency of the rotating wire to develop nodes and depart from the form of a true arc. It was, however, possible to conduct experiments on un-cracked blue-black wire taken from drums returned to the works, and to prove that the presence of the oxide layer did not reduce the number of revolutions required for fracture. Probably a weakness in this experiment was that oxidation and application of cyclic stress did not proceed simultaneously, but it did at least indicate that oxide intrusions at the surface of the wire (Fig. 5) need not have a weakening effect.

The fatigue limit for copper is reported to be slightly higher in a vacuum than in air. Acid and alkaline impurities in the atmosphere (CO_2, SO_2, NH_3, etc.) are said to play little or no part in the action which results in a reduced fatigue limit in ordinary air, but oxygen and water vapour do play an important part.[3]

Cause of Fracturing

In view of the failure to reproduce fracturing or cracking in the many experiments carried out, the problem whether fracturing in service arose from static or cyclic stress remains undetermined. The difficulty with the fatigue hypothesis is to account for cyclic stress. At first sight, nothing looks more compact and less likely to vibrate than 19/0·083 in. hard-drawn copper strand, weighing about one and one quarter tons, wound on a strongly-made drum, but a similar remark could be passed about a drum of lead-covered telephone or power cable, and yet the lead sheathing on cable has been known to crack in transport. A drum of strand as a whole, like other items of merchandise, does vibrate during transport, and it is also reasonable to suppose that loose turns can vibrate separately from the mass of strand, but there was no clear evidence to support the view that fracturing occurred in loosely-wound drums. Distortion of drums through shrinkage in drying could conceivably introduce some slackness in turns of strand near flanges, but again there was no clear evidence at the time that this was so. No rubbing or pressure marks that could have been caused by vibration in transport were visible on the wires. Either particular boards emitted a vapour containing a specific cracking reagent for copper or, what is perhaps more likely, they were at a critical stage of seasoning to provide a rate of corrosion sufficient to cause fracture with the required type of vibration.

Acknowledgments

The author wishes to thank Metal Manufactures, Ltd., for permission to publish this paper; the various government and municipal departments who contributed samples or otherwise assisted in the study of the problem, especially Mr. H. G. West of the New South Wales Department of Railways, Electrical Branch, and Mr. L. E. Samuels of the Defence Standards Laboratories; and Messrs D. B. Thompson, I. K. Kirkpatrick and G. Fogliarti for assistance in the investigation.

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Aluminium in New Zealand

NORTHERN ALUMINIUM CO., LTD., has announced that it will shortly establish a new branch of its aluminium fabricating industry in New Zealand. This decision is the outcome of discussions held between the company and the New Zealand Government over several months. The new plant will have an initial production capacity of 5,000 tons per annum of aluminium sheet and foil products, and 2,000 tons per annum of aluminium wire and cable for electrical transmission lines. The location of the plant has yet to be decided; alternative sites in the North and South Islands of New Zealand are being considered. The primary aluminium to be used in the New Zealand plant will be supplied from Canada.

The project will require a total investment of approximately £2,000,000, almost the whole of which will be provided by Aluminium, Ltd., and Northern Aluminium Co., Ltd. The plant will be of the latest design, incorporating the best techniques from British and Canadian experience, and will be planned to supply practically all New Zealand's requirements of sheet and cable products, and to allow for expansion in all fields as required. It is expected that this new industry will become of increasing importance to the New Zealand economy, since among its products will be aluminium sheet for roofing and siding in building construction, for vehicle bodies of all types, and for the household equipment industry. Additionally, it will cater for the packaging industry and supply many types of electric cables for power transmission.

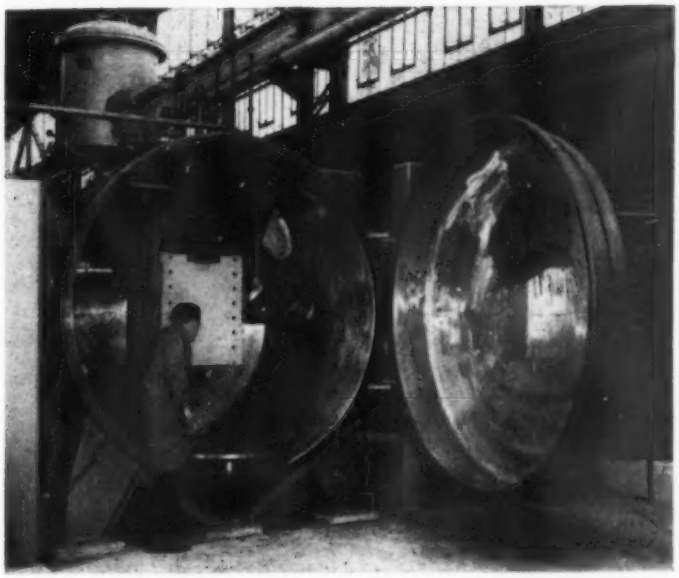
The general manager of the New Zealand branch will be Mr. T. E. L. Ashley, who has spent over 30 years in the aluminium industry in England, and has been manager of the plant at Banbury for the past 25 years.

Aluminium Superstructure

ERECTION of the 1,040 tons of aluminium in the superstructure of *Oriana*, the 40,000 ton Orient liner now building at the Barrow-in-Furness shipyard of Vickers-Armstrongs, has commenced. The ship is due for launching in the autumn of this year. The work is the largest all-welded aluminium superstructure ever built into a ship—in fact, there is more aluminium than in any other ship's superstructure because previously steel stiffeners have been used. It comprises five decks, two bridge decks, and all upper works, complete with internal structures. The total area of bulkhead and deck plating is nearly 350,000 sq. ft., and there will be 20 miles of special extruded aluminium section. Approximately 90% of the structure is prefabricated and welded in the assembly shops, where work on it started in mid-January, before being built into the ship. Welding is carried out by hand and automatic machines, using the argon gas shielded metal arc process.

Vacuum Melting of Metals

New Plant Installed at Sheffield



600 lb. Wild-Barfield N.R.C. high frequency vacuum-induction melting furnace.

IN recent years there has been a continually increasing demand for new and better materials to keep pace with the needs of design engineers. With a view to meeting this challenge, Wm. Jessop & Sons, Ltd.* the Sheffield steelmakers, have concentrated in recent years on a programme of intensive research into the development of new alloys and new metals. These investigations led to the introduction of new processing techniques, one of the most outstanding being vacuum melting.

Although melting *in vacuo* is not a new technique, its conception going back to the last century, it is only during the last decade that it has achieved importance as a commercial production method. Moreover, during the same period the potentialities have increased considerably due to the higher vacuum now attainable. Whereas early vacuum melting was carried out at pressures of 1–10 mm. Hg, and could more properly be regarded as protective-atmosphere melting, pressures as low as 10^{-3} mm. Hg are possible in present day furnaces, in which significant vacuum purification is possible, and which have opened up a new field of metallurgy.

Early vacuum melting was carried out in high frequency induction furnaces, but in the case of some of the newer metals such as titanium, which must be melted *in vacuo* or under an inert gas, crucible limitations rule our vacuum-induction melting. Pioneers in this field used tungsten electrodes for arc melting such metals in a water-cooled copper hearth or crucible under an argon atmosphere. Later developments led to consumable electrode arc furnaces operating in a high vacuum. It was this type of furnace which Jessops put into full-scale operation in 1956, the two units being capable of producing titanium ingots with a diameter up to 20 in., and up to 1 ton in weight. These furnaces are also used for melting zirconium, which finds its principal application in the nuclear energy field.

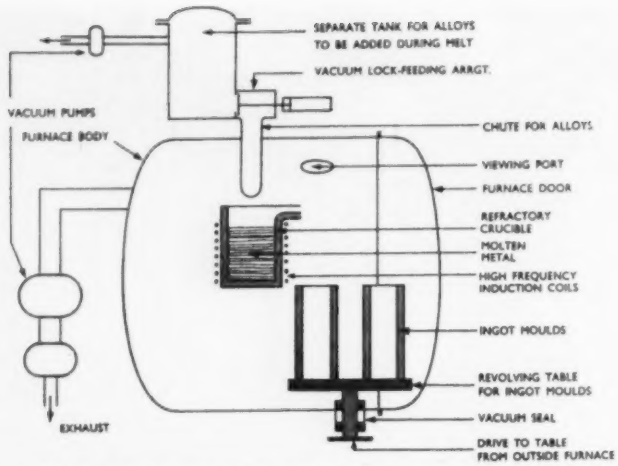
* Now Jessop-Saville, Ltd.

During the development work on a smaller laboratory consumable electrode furnace, a temporary shortage of titanium sponge provided an opportunity to try the effect of remelting steel bars *in vacuo*. The results were definitely encouraging, as the technique was found to improve considerably the characteristics of many steels. The consumable-electrode arc furnaces referred to above have a melting capacity of 30 cwt. in the case of steel.

It was soon realised that, with increasing demand for these new materials, the plant would not satisfy all requirements, particularly for the larger forgings, and the decision was made to increase production facilities. A new Heraeus consumable arc melting furnace has been installed and is now fully operational. This is capable of melting titanium ingots up to 24 in. in diameter and in excess of $2\frac{1}{2}$ tons in weight, which is believed to be the largest which can be made this side of the Atlantic.

In parallel with the work on vacuum-arc melting, the Jessop Research Department was engaged in investigations into the possibilities of vacuum-induction melting, which can, of course, be used with alloys for which the production of an air-melted electrode as a starting point is not possible. A 20 lb. high frequency induction furnace was used in this work, and a certain amount of commercial work was carried out in it, including the provision of vacuum melted cast sticks to serve as raw material for the makers of precision castings by the lost-wax and other similar processes. The results of these investigations were also promising—so much so that a 600 lb. Wild-Barfield N.R.C. high frequency induction melting unit has been installed recently and is now fully operational.

This is the largest of its type in Europe, and the combination of arc and induction units provides the largest operational vacuum melting plant outside the U.S. It is, perhaps, unique in that the vacuum melting of steel by the consumable electrode arc and induction methods is carried out in the same plant as is used for



Simplified arrangement of the 600 lb. vacuum-induction melting furnace.

producing vacuum melted ingots of titanium and zirconium. This arrangement has its advantages, in that investigation of problems arising in one material may produce results of benefit to the others.

Vacuum-Induction Furnace

The Wild-Barfield/N.R.C. 600 lb. vacuum-induction melting furnace is designed for semi-continuous operation, provision being made to accommodate sufficient ingot moulds for several heats on the rotary mould table, and for charging the furnace through a bulk charging hopper without breaking the vacuum in the melting chamber.

The principal unit of this installation is a horizontal vacuum chamber, constructed of stainless steel, approximately 7½ ft. in diameter by 9 ft. long. The end of this chamber is sealed by hinged door and the whole of the chamber and door is water cooled by copper coils, brazed to the outside of the unit. This chamber contains the high-frequency induction melting coil which is designed to tilt about the pouring axis, and immediately in front of and below the furnace there is a rotary mould table which allows several ingot moulds or castings to be poured from one melt. Provision is made for the observation of all stages of the process through three observation windows, each equipped with shields and wipers.

External controls are provided for the following equipment and operations :

(1) Bridge breaker for breaking top layer of unmolten metal in the crucible.

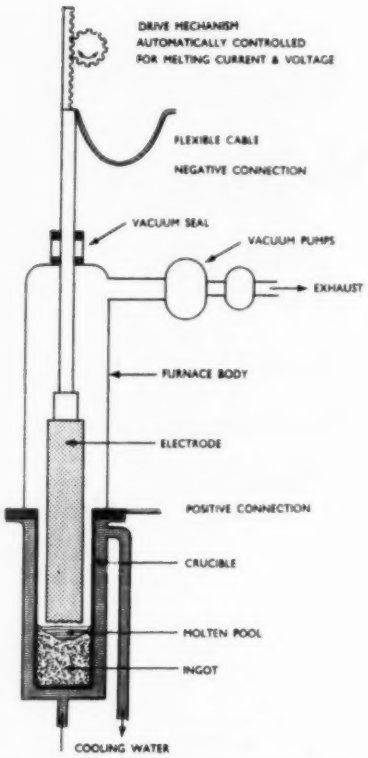
(2) Immersion thermocouple pyrometer for temperature measurement.

(3) Sampling device which can be extracted through an air lock without breaking the main tank vacuum for compositional control during melting.

(4) Sighting tube for optical pyrometer readings.

(5) Internal light assembly for illumination of the tank interior.

A cylindrical chamber, situated on top of the horizontal melting chamber contains the alloy charging mechanism, consisting of a 2,200 cu. in. bulk charging



Simplified arrangement of the consumable electrode vacuum-arc melting furnace.

hopper, holding 300 lb. of material, and four smaller hoppers, each of 90 cu. in. and holding a further 12 lb. of alloys each. Both bulk charge and alloys are delivered to the crucible by a vibrating feeder through a 6 in. diameter vacuum lock. Alloy buckets are individually tripped by solenoids operated from the control panel. The vibrator feeds into a chute which swings over the crucible, and an interlock is provided which prevents the vibrator from operating unless the chute is in position. The whole of this chamber may be refilled without breaking the vacuum in the main tank by closing the 6 in. diameter vacuum lock. A special pumping line is provided to evacuate this chamber after it has been recharged with material.

The pumping system comprises two oil booster pumps backed by a Roots pump, which in turn is backed by a single-stage mechanical rotary pump. It is designed to handle the gases from 600 lb. molten charge during melting, purifying and alloying. The pumps have the necessary capacity for disposal of the gases as they are given off from the melt, and pneumatic operation is provided for all the vacuum valves used during the pumping cycle. The vacuum system consists of a large 16 in. diameter high vacuum manifold and a 6 in. diameter rough pumping line connected to the end face of the melting chamber to enable rapid and complete evacuation of the chamber. This combined system will pump the furnace chamber from atmospheric pressure to a pressure of one micron Hg in 15 minutes. Vacuum gauges measure the furnace tank pressure from 1 micron to atmospheric pressure, the vacuum instruments con-

sisting of one alphatron gauge and a five point thermocouple vacuum gauge.

Although the largest of its kind in Europe, this furnace has a much smaller capacity than the 3,000 lb. units installed in the U.S. This may prove to be about the limit, since as the size increases the supply of adequate power *in vacuo* becomes more and more difficult. The earlier policy of restricting the coil voltage has had to be abandoned with the larger production furnaces, owing to the difficulty of designing electrical systems to operate at the high amperages needed. Recent production furnaces use coil voltages up to 800V. and by careful attention to chamber and coil design, and by insulation of the coil, electrical discharge problems have been avoided.

The power supply for the Jessop-Saville furnace is a 200 kW. motor-alternator set working at 400 V. and 3,000 c./s. Operating platforms are provided for easy access to the controls and observation windows, and the control panels for the electrical and pumping systems are mounted on the main operating platform.

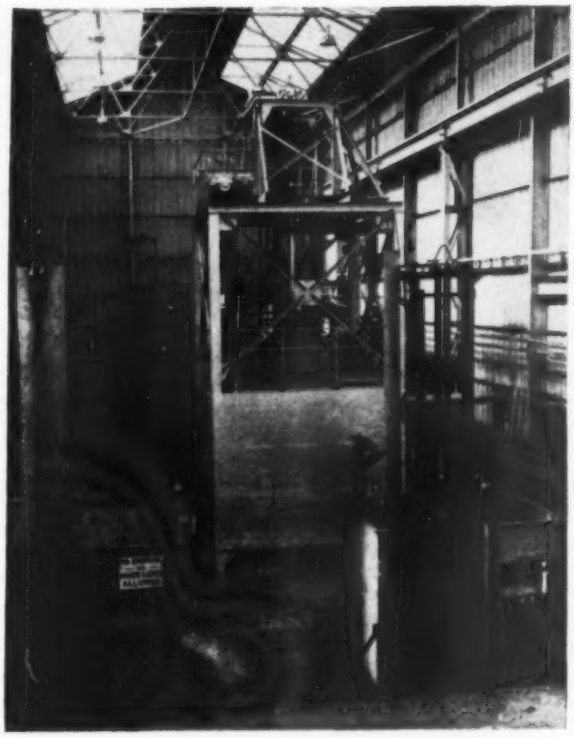
Vacuum-induction melting in addition to providing higher quality materials than melting in air, has also made possible the production of alloys which, because they contain elements which are readily oxidised, cannot be produced by conventional air melting methods. The Jessop Saville unit will be used for melting iron, nickel and cobalt base alloys.

Vacuum-Arc Furnace

The Heraeus consumable arc melting furnace consists of a large vacuum-tight vessel evacuated by pumps which are capable of handling large volumes of gas at high vacuum. The actual melting is carried out in the water cooled copper crucible which forms the lower half of the furnace.

The electrode is charged from underneath by a moving crucible trolley, in contrast to the earlier production furnaces, in which the water jacket is a fixture and the whole of the top part of the furnace is removed by crane. In the case of titanium, the electrode is formed by welding together compacts made by compressing mixtures of titanium sponge and alloying additions in a hydraulic press. Steel electrodes may be castings of air melted steel or forgings made from an air melted ingot. Whilst the former are to be preferred for economy, they require special cylindrical moulds of unusual length/diameter ratio. The electrodes must be cleaned of all scale before melting.

Inside the furnace, the electrode is attached to a feeder rod, and by applying drive to the latter the electrode can be raised or lowered, to control the melt. The feeder rod also carries the melting current, through sliding vacuum seals, from the electrical busbars down to the electrode. The melt is started by striking an arc between the bottom of the electrode and a small charge placed at the bottom of the crucible. The heat generated by the arc provides sufficient heat to melt the tip of the electrode, and molten metal sprays down to form a pool, which, when solidified, forms the ingot. As the molten pool is only of small dimensions, great care must be taken to ensure that melting conditions are kept constant throughout the melt. A view of the melt is projected on to a screen at the melting desk, alongside the many electrical gauges. From these, the melting operator is able to assess the furnace conditions and make any necessary modifications to control the melting to a rigid specification.



Heraeus consumable electrode vacuum-arc melting furnace

Electrode feed in either direction is controlled by two motors acting independently but coupled to the feeder rod through a differential gearbox. One motor tends to drive the electrode downwards and is energised from the arc supply ; the other motor tends to drive the electrode upwards at a predetermined rate. Final motion of the electrode is thus the resultant of the two effects through the differential gear box. By this means, the usual disadvantage of inertia associated with a reversing motor is eliminated, and rapid response to correcting signals is achieved.

Errors in either arc voltage or current are detected by a sensitive relay and used to operate heavy-duty thyratrons which vary the predetermined speed of the ' upward ' driving motor. A further important feature of the control equipment is that allowance can be made for the difference between measured and true arc voltage by automatic correction within the controller for the voltage drop along the feeder rod and electrode, provided the appropriate constants are known in advance.

The vacuum equipment is capable of holding melting pressures below 1 micron, and at this pressure the arc is very stable. There are two pumps fitted for the final evacuation of the furnace—a Roots pump and an oil booster pump. This arrangement has the advantage that it would prevent steam pressure build-up should the copper crucible be penetrated by the arc, and it is not as costly as using Roots pumps alone. The combined speeds of these pumps is 4,000 l./sec. for air and 10,000 l./sec. for hydrogen.

The furnace components—pumps, valves, etc., are actuated remotely from a control cabinet. There is

provision for automatic operation of all vacuum equipment, so that, when the furnace is closed, evacuation is taken through all its stages without supervision. This automatic system also safeguards the vacuum equipment in cases of component failure. For safety, the arc current is interlocked with all operations which, if faulty, could lead to dangerous conditions. A section of the cabinet is devoted entirely to indication of possible breakdowns, so that rapid rectification can be made.

Titanium ingots made in this furnace range from 9 in. diameter (120–420 lb.) through sizes 12, 16, 20 and 24 in. (exceeding 2½ tons in weight). As mentioned earlier, the plant is capable of producing zirconium ingots, but it is likely that initial production will be confined to ingots up to 800 lb. in weight. Steel ingots up to approximately 3 tons in weight can also be produced in the same sizes.

Advantages of Vacuum Melting

Vacuum melting will not satisfy all the demands of the engineer made on the metallurgist but it does represent a considerable advance in many metallurgical problems. For instance turbine and compressor disc materials used in gas turbine aircraft engines must be virtually free from non-metallic inclusions. Vacuum melting can not only ensure this, but also provides the designer with enlarged scope for even more highly stressed conditions. This freedom from non-metallic inclusions also ensures that the transverse ductility of forged discs is improved. Tensile tests on vacuum melted 12% chromium steel discs have, for instance, given elongation values four times greater than those obtained on discs made from air melted materials.

In ball bearing and ball race steels, too, it is particularly important that there is freedom from non-metallic inclusions which might give rise to premature failure. Jessops have concentrated much effort in this direction, and their vacuum melted ball race steel with extremely high standards of cleanness are now being widely tested. A further instance where freedom from inclusions is of the greatest importance is in dies for the production of plastic components with as near perfect surface finish as possible.

Vacuum melting reduces the total gas content of the metal. Tests have shown that with air melted steel, remelting in vacuum reduces the total oxygen, hydrogen and nitrogen content of the steel from 600 parts per million to 200 parts per million. This feature of the process is particularly useful in the production of stock for precision castings or for remelting prior to precision casting, for in this way the undesirable blow holes and gas pockets can be obviated. The production of certain steels with low hydrogen content minimises the need for long immunisation heat treatments necessary to avoid the danger of hair line cracking.

Induction vacuum melting has made possible the production of alloys which, because they contained elements which readily oxidised, could not be produced by conventional air melting methods. This new technique now opens up fresh fields in the development of high temperature materials. One such alloy, Jessop G.64, contains high percentages of aluminium and titanium, and can only be made satisfactorily in a vacuum melting furnace. It has excellent high temperature properties and is being assessed for stator and turbine blade applications.

The advent of nuclear power plants has posed further problems for the metallurgist in the demand for new materials. One of these is the production of zirconium ingots, which can only be achieved by vacuum melting: Jessops are developing a range of zirconium alloys, some of which are already in commercial production. In many nuclear applications it is essential that certain tracer elements in steel be reduced to an absolute minimum. The vaccum melting technique permits close control of the chemical composition of every melt, and enables certain elements to be completely removed and others kept to the specified minimum.

Future Developments

As was mentioned earlier, some authorities believe that there may be a practical limit to the size of vacuum induction furnaces at about 2–3 tons, due to electrical and crucible problems at larger sizes. This size limit should offer no restrictions for applications at present being considered, but it may limit the price reduction of bulk vacuum melted products. In the case of vacuum arc furnaces, no such size limitations are foreseen, and it is considered that 40–50 in. diameter furnaces melting 15–20 tons of steel are a practical possibility today.

Two new vacuum melting processes are attracting attention at present. In the first of them—skull melting—a consumable electrode is melted *in vacuo* into a shallow copper hearth, held molten under argon by non-consumable tungsten or graphite electrodes, whilst bath samples are taken and alloying additions made, and then cast by lip pouring into conventional ingot moulds. In the electronic bombardment melting technique, the electrode is melted by high voltage electron bombardment under a very high vacuum, the molten metal collected in a water cooled hearth, and the surface of the melt similarly heated by electron bombardment. It is claimed to offer opportunities for a greater degree of perfection than any other process, but is costly owing to the electrical plant and the high vacuum plant required. It cannot, of course, be used for alloys containing volatile constituents.

At the moment, in spite of the attractions of these newer processes, it is believed that vacuum induction and consumable electrode vacuum arc melting will account for the bulk of production of vacuum melted metals for many years to come.

New Walking Dragline

ERECTION of a £396,000 walking dragline is at present in progress at the Yarborough ironstone quarry, Scunthorpe, of the Ore Mining Branch of The United Steel Cos., Ltd. The 790-ton machine, known as a W600, is expected to begin work in June. It has a 186 ft. long jib and its 10 cu. yd. bucket will enable it to strip 15 tons of overburden at each 'bite.' The iron ore thus uncovered will be removed by smaller mechanical diggers. Initially, the depth of overburden will be 30 ft., increasing as the quarry is exploited. The W600 is the second machine of its kind in the Scunthorpe area, the previous one having been in operation at the Ore Mining Branch's Crosby Warren quarry for the past two years. Both quarries are engaged in supplying the adjacent works of Appleby-Frodingham Steel Co. with iron ore. When the new dragline starts work, the Yarborough quarry will be able to provide between 36,000 and 40,000 tons of iron ore per week for the Appleby-Frodingham blast furnaces.

Production of Casting Pit Refractories

New Tunnel Kiln Commissioned

Dr. A. T. Green, Director of Research of the British Ceramic Research Association, pushing the first truck-load of hollow refractories into the new kiln at the works of Thomas Marshall & Co. (Loxley), Ltd., Sheffield. Watching at the opening ceremony are Mr. T. Marshall (centre) Chairman of the Company and Mr. A. Marshall, Managing Director.

DURING the last few years, steel production has been running at an annual rate in the neighbourhood of 20 million tons, as compared with 12 million tons in 1945, and this expansion in the industry has meant a corresponding increase in the consumption of refractories. Some 60% of all the refractories made in this country are used by the iron and steel industry, and the last thirty years has seen the establishment of close co-operation between the refractories and the iron and steel industries. Dr. A. T. Green, C.B.E., Director of Research of the British Ceramic Research Association, stressed the importance of this link recently, when he officially opened the new tunnel kiln at the works of Thos. Marshall & Co. (Loxley), Ltd., Sheffield, by pushing into it the first truck-load of work. He referred to the joint research and other committees in existence, and to the progress that had been made in improving the quality of refractories, instancing the blast furnace, where, despite increased size and rate of blowing, the consumption of refractories per ton of metal smelted was less than formerly, a result which had been made possible by the production of refractories with enhanced properties.

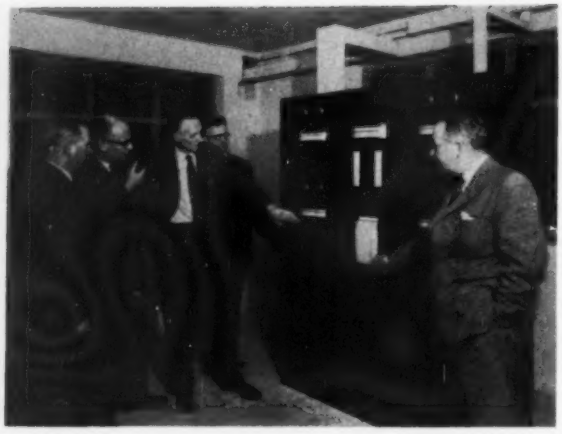
The new kiln has a capacity nearly twice as great as an older kiln of almost the same length. The greater width of the trucks for the new kiln (right) is clearly shown in the picture, as are the shaped bricks which key with bricks in the kiln wall and prevent the heat from reaching the wheels and rails.

Hollow Fireclay Refractories

Turning to casting pit refractories—the principal product at the Loxley Works—Dr. Green said the firms engaged in their manufacture had made considerable progress in the development of products with better properties, and the new kiln, besides increasing output, should, by facilitating control of the process, lead to hollow fireclay refractories of improved quality, which, in turn, would make their contribution to the production of better steel.

The firm of Thos. Marshall & Co. (Loxley), Ltd., is the direct descendent of an enterprise started 150 years ago to make crucibles from local clay, and although to-day the bulk of the output from the Loxley Works comes under the heading of casting pit refractories, the company is also interested in firebricks, insulating bricks, carbon bricks, etc., made by other members of the Marshall group for service in this country and abroad. Last year, £220,000 worth of all types of product was exported by the group to twenty-nine different countries, including one behind the iron curtain.

In view of the need for constant improvement in manufacturing techniques and processes, a comprehensive three-stage programme of kiln development and modernisation has been planned for Loxley at an estimated cost of £100,000, of which £50,000 has been spent on the recently completed first stage, the principal feature of which is the new tunnel kiln.



Mr. K. W. Cowling (third from left), Technical Director of the Company, explaining the operation of the control panel of the new kiln.

Claimed to be the largest in the U.K. to be used for firing hollow fireclay refractories, the new oil-fired kiln is almost 200 ft. long, and has a capacity of 140 tons a week. It is built next to a kiln of similar design which, erected in 1933, was the first of its kind in the U.K., and, although the new kiln is only a little longer than the old one it has twice the capacity.

Following the normal design practice for tunnel kilns, there are three sections: preheating, firing and cooling zones. The flow of gases is in the direction counter to the travel of the loaded trucks, which are therefore preheated in the primary section by the hot gases passing to exhaust. The heat in the loaded trucks entering the cooling zone from the main or firing zone preheats the air which is used for combustion of the fuel and for drying the ware in the dryer. As a result, both the gases leaving the exhaust end and the trucks and refractories leaving the other end of the kiln are cooled down, and it is this full use of the heat generated in the kiln which gives the process such a high thermal efficiency.

Automatic Temperature Control

The kiln is fired by four main special type burners supplied by Gibbons Bros., Ltd., Dudley, the majority of the oil handling plant being by Reavell & Co., Ltd., Ipswich, and Duncan Low, Ltd., Glasgow. Fuel oil consumption is estimated at 13 tons per week, equivalent to about 22 gallons of oil per ton of fired ware. At present two compressors and one oil pump are available, and this equipment will be duplicated to deal with fuel supplies to three kilns. Control of the finishing temperature is by means of separate automatic controls at each burner, the pyrometric and temperature control system being by Electroflo Meters, Ltd. Recirculation is carried out in two separate zones in the preheating section of the kiln to ensure temperature uniformity, which is guaranteed to be within 10°C. throughout the car load. Additional burners in the preheat section can be brought into operation if desired. The main firing zone is semi-muffled so that, although the ware is protected against direct impingement of the flame, hot gases from the combustion chamber enter the kiln below the car deck and, if it is required to introduce more top heat, through damper-controlled ports above the muffles.

The exhaust gases from kilns firing fireclay of this type contain sulphur trioxide originating mainly in the pyrites in the clay. Apart from the damage which may result from its release into the atmosphere, it can cause serious distortion of the brickwork of the kiln. To counteract these effects, the exhaust gases are conditioned so that the obnoxious gases are rendered non-corrosive and air pollution is reduced. The gas treatment equipment is based on the joint recommendations of Shell Mex & B.P., Ltd., and Imperial Chemical Industries, Ltd., and this is believed to be the first instance of ammonia being admitted to a tunnel kiln for this purpose. The control panel was made up from standard components in Marshall's own fitting shop, following original experimental work on one of their other kilns, in association with Shell Mex & B.P., Ltd. An additional recirculation system has been incorporated in the kiln to deal with this treatment of the exhaust gases, and a venturi-type chimney is used to dilute the gases as they enter the atmosphere. The dryer, which is provided with ample recirculating fans, is as long as the kiln, and is expected ultimately to deal with the drying of the ware for the new kiln and the other two kilns already in use.

The main construction of the kiln is typical of its type, and wall and crown are well insulated with materials supplied by Marshall's subsidiary company, Kingscliffe Insulating Products, Ltd. Apart from the foundations, which were Marshall's responsibility, the whole of the construction work on the kiln and dryer has been carried out by the contractors, Gibbons Bros., Ltd.

Better Products

A high degree of technical control can be obtained with this type of kiln, ensuring truer shape and size of the products. The inherent advantages of continuous operation lend themselves to the modern automatic and semi-automatic production lines throughout the Loxley Works. Ultimately, all the tunnel kilns will be converted to oil-firing, and, coupled with the replacement of the older type of periodic kilns by Temco kilns and improvements in layout, will provide higher productivity and greater firing efficiency throughout the works.

In the meantime; development work on very high quality hollow refractories has reached the pilot plant stage. Fireclay ladle nozzles are not good enough for use with certain steels, such as those with high sulphur, lead, etc. content, because of the excessive wear. To meet the need for something better, high alumina inserts are being developed to provide controlled teeming nozzles. It is, of course, desirable that there should be some wear, to compensate for the reduced ferrostatic head as the ladle is emptied, the aim being to formulate the nozzles so as to achieve the right balance. The material used calls for a high firing temperature, and a feature of the pilot plant is a small catenary arch kiln capable of being heated to 1,750°C.

G.E.C. Turbo-Blower Contract

A CONTRACT, valued at cover £200,000, has been placed with The General Electric Co., Ltd., for the supply of two turbo-blowers for the furnaces at the new works of the South Durham Iron and Steel Co., Ltd., West Hartlepool.

Welding Structural Aluminium Alloys

Locomotive Engineers See New Developments

WHEN members of the Institution of Locomotive Engineers visited the Research Laboratories of The British Aluminium Co., Ltd., at Gerrards Cross, recently, they saw something of the progress being made in the fusion welding of aluminium and its alloys, with particular reference to their use in railway rolling stock. Although aluminium sheet has been in continuous service on electric rolling stock in this country for some forty or fifty years, it is only since the war that interest in light alloys for this purpose has really developed, but whereas sheet was the only wrought form in which aluminium was used in the early applications, advantage is being taken today of the wide range of sections that can be made by extrusion.

Wrought aluminium alloys for structural use may be divided broadly into two classes, the non-heat-treatable and the heat-treatable. The former are fairly strong in the annealed state—15 tons/sq. in. U.T.S. for the 3·5% Mg, 0·5% Mn alloy, and 18·5 tons/sq. in. for the 5% Mg, 0·5% Mn alloy—and the strength of a butt welded joint is almost equal to that of the annealed metal. By cold working, the tensile strength can be increased, but the strength of a butt welded joint remains the same, because of the annealing effect of the welding heat on the material adjacent to the weld. The heat affected zone can be narrowed by high speed welding and it is possible to obtain a 10% increase in strength. The improvement is, however, somewhat unpredictable and difficult to control with manual welding; the chances of success are much greater with automatic welding.

Welding heat-treatable alloys of the H10 and H30 type (0·7% Mg, 1·0% Si, 0·5% Mn) results in a pronounced strength reduction from, say, 18–19 tons/sq. in. to 12–13 tons/sq. in. The strength of these alloys stems from a solution treatment followed by a precipitation treatment, and welding destroys the structure produced by the original heat treatment. Speed of welding has more influence on the resulting joint strength than in the case of work-hardened alloys. By welding ¼ in. H30 at a very high speed (60–70 in./min.), 85–90% of the strength of the fully heat treated material can be recovered by ageing after welding: automatic welding is thus again advantageous. Joints in these alloys made by the inert-gas metal-arc (M.I.G.) process are somewhat stronger than those made by the inert-gas tungsten-arc (T.I.G.) process.

Welding Processes

Oxy-acetylene welding can be used with pure aluminium and the lower strength alloys, but it does not readily give efficient welds in the 3·5% Mg and 5% Mg alloys: it is best employed where the metal is thinner than ¼ in. A flux is required whose residue is corrosive and must be removed after welding.

Metal-arc welding with flux-coated electrodes is possible for pure aluminium and the heat-treatable alloys of the aluminium-magnesium-silicon type. D.C. power is used and the equipment is simple, but weld quality and appearance do not usually compare with inert-gas shielded-arc processes. Again, flux removal is necessary after welding.

The inert-gas tungsten-arc process, often described as the argon-arc process, but for which the abbreviation T.I.G. (tungsten, inert gas) is now being used, finds wide application for high quality sheet metal work. It employs an A.C. power source, with special facilities for arc starting and stabilising, connected to a torch containing a non-consumable tungsten electrode round which passes a stream of the inert gas, argon. The arc disperses the oxide film on the aluminium and the argon prevents further oxidation; thus, no flux is required. A filler rod may be used, or not, as circumstances demand.

The inert-gas metal-arc process was introduced into Britain in 1952, and has become widely known under trade names of equipment, e.g. Argonaut and Sigma. Recently the term M.I.G. (metal, inert-gas) process has become popular as a brief designation. This process employs D.C. power, and an arc is struck between a consumable aluminium electrode and the work. The electrode is in the form of a wire stored on a reel and fed to the welding gun automatically. The tip of the wire and the molten weld metal are protected from oxidation by a stream of argon. An essential feature of the process is the use of high current densities in the electrode, the minimum value being in the region of 35,000 amps/sq. in. Under these conditions "projected metal transfer" is obtained, tiny droplets of molten electrode being transferred at high velocity through the arc to the work in the direction in which the electrode is pointed. It is this feature which facilitates fillet welding and makes all-position welding relatively simple. The process is characterised by very high welding speeds and is amenable to partial or full mechanisation.

In the United States, the 5% Si alloy has been the "universal" filler wire* from the early days. It has good resistance to hot cracking and is compatible with alloys of the aluminium-magnesium-silicon type. With the development in Europe of the non-heat-treatable aluminium-magnesium alloys, the 5% Mg alloy was adopted as filler, since the aluminium-silicon alloy was not suitable. It is possible to use the aluminium-magnesium alloy for welding the heat-treatable aluminium-magnesium-silicon alloys, with a result which has good resistance to hot cracking, although possibly not quite as good as with aluminium-silicon filler. The joints are stronger and more ductile, however, and if corrosion tests show no undesirable tendencies—they have not done so as yet—the 5% Mg alloy may be used for welding H30. Where heat-treatable and non-heat-treatable alloys are joined, the 5% Mg alloy is recommended: also where joints in aluminium-magnesium-silicon alloys are to be anodised. Pure aluminium is used as a filler in welding pure aluminium and the 1¼% Mn alloy, and the latter may also be welded with 1¼% Mn alloy filler.

Welding Thin Sheet

The welding laboratory was the scene of an interesting display of applications of the shielded arc processes. The

* Electrode wire in the M.I.G. process.

T.I.G. process still finds widespread application, and an interesting example on show was a milk churn welded without filler wire to give a joint of very neat appearance It is not a fast process, and it is not at its best in fillet welding.

On the other hand, the M.I.G. process has its limitations for welding thin material. Until recently this process could not be used for the manual welding of metal thinner than $\frac{1}{8}$ in., but methods now exist which permit the welding of material down to 0·064 in., or thinner. For thin material it is necessary to reduce the welding current, and to maintain the necessary minimum current density on the electrode : this means a corresponding decrease in wire size. The drawback to using wire less than about $\frac{3}{64}$ in. diameter lies in the difficulty in pushing it through some 10 ft. of flexible conduit to the welding gun, as is done with the thicker wire on currently available equipment.

The Research Laboratories of the British Aluminium Company have experimented with the use of smaller diameter electrode wires, for the feeding of which a drive mechanism has been incorporated in the welding gun rather than near the wire storage reel as in earlier equipment. The B.A. experimental gun, which was demonstrated to the visitors, is an adaptation of the normal equipment, in that the drive is transmitted from the conventional unit, by means of a Bowden cable, to a pair of small serrated rolls at the gun. These rolls feed the fine wire through the gun from a small reel attached to it. The current is fed through the rolls, and the pressure between them needs careful adjustment to obviate slip, on the one hand, and cutting through the wire, on the other. Grease and dirt must be removed from the wire, which is pretreated with sodium zincate solution. The unit has been used for automatic welding, when the higher welding speed permits the use of $\frac{1}{16}$ in. diameter wire. As a modification of the existing design, it would be possible to have the reel on the welder's person, and so reduce the weight of gun to be handled.

American West-ing-arc equipment, now to be marketed in the U.K. by the Rubery Owen Group under the name Rowen-Arc, was also designed for using thin electrode wire, and has a motor-drive built into the gun, which obviates the Bowden cable. It also differs from the B.A. gun in that, whereas in the latter current is fed to the wire through the feed rolls, a contact tube is used for this purpose in the Rowen-Arc gun.

Fatigue Investigations

Investigation of the fatigue properties of aluminium and its alloys has been in progress for many years, and many reports are available giving information on the behaviour of these materials, both in the laboratory and in service. Much of this work has, however, been carried out by the aircraft industry, using materials and conditions which are not normally employed in general engineering practice. The increased use of low and medium strength alloys in structures subjected to fluctuating load has created a need for more information, particularly on the behaviour of joints in these materials. Improvements in techniques in the past ten years have established welding as the most important method of making joints between structural members, but the effects of welding on the fatigue properties of the joint have only recently been investigated on any appreciable scale.

During the past two years, the British Aluminium Company has carried out an extensive programme of work to determine the fatigue properties of butt-welded 5% Mg, 0·5% Mn alloy when subjected to reverse bending. Visitors were shown the results of these tests, together with data indicating the value of various post-weld treatments designed to improve the fatigue strength of the weldment.

In a series of tests on $\frac{1}{4}$ hard 5% Mg, 0·5% Mn alloy, a butt-welded joint showed a reduction in fatigue strength compared with the parent plate. The fatigue curve for the plate in the annealed condition fell midway between the $\frac{1}{4}$ hard plate and the welded $\frac{1}{4}$ hard plate, and similar results were obtained with welded $\frac{1}{4}$ hard plate when the weld reinforcement was removed. It seems, therefore, that the lowering of the fatigue properties on welding is due in part to softening of the heat-affected zone, and in part to the notch effect due to the weld reinforcement.

Among the methods of improving the fatigue strength of weldments that have been investigated is the introduction into them of stresses which will minimise the effect of service stresses. In tests on longitudinal fillet welds at the junction between the web and the flange of an I-beam, failure in fatigue often occurred just beyond the end of the weld run, where an unfavourable system of internal stress resulted from the welding operation. Improvement could be effected by heating a suitably chosen spot near the point of failure to a temperature in the region of 300° C., so that yielding could occur at the spot and the internal stress system after cooling would be more favourable from the point of view of fatigue. When this technique was first suggested, it was thought that the high conductivity of aluminium would prevent the attainment of the necessary high temperature gradient, but this view has been shown to be unduly pessimistic. The British Welding Research Association is approaching the problem from another angle, and is investigating the use of pressure instead of heat as a means of producing a suitable stress system.

Coupled with the work on the fatigue properties of various alloys in both the welded and unwelded states, records have been taken by means of dynamic strain gauges of the stresses in a London Transport train bogie in service. The seven miles of chart produced in this investigation are at present being analysed by the Aluminium Development Association, who are interested in the design of a bogie in aluminium.

David Brown Acquire U.S. Technique

An agreement has been signed giving David Brown Industries, Ltd., exclusive manufacturing rights in Britain of a patent form of radiation shielding, perfected in America by Knapp Mills, Inc., of New York. Claimed to provide the most efficient form of shielding against radiation yet devised, the process has particular application in the field of nuclear power. In this connection it has already been successfully applied on a large scale in the U.S.A. in the shielding of radio-active materials in atomic-powered ships, and in space missiles. It has also been extensively used in conjunction with radiation equipment developed for special application in agriculture, medicine and biology. The process also has extensive application in the chemical processing industry, where it has been found eminently suitable for use where highly corrosive liquids or chemicals need to be contained, or where radioactive corrosives must be processed and shielded. Manufacture of the shielding will be carried out at the David Brown Jackson Division, Salford.

Correspondence

Deformation Mechanisms in Magnesium and Magnesium-Aluminium Alloys

The Editor, METALLURGIA.
Sir,

As I am currently interested in the mechanical properties of magnesium under various forming conditions, I have recently had occasion to consult the paper by R. D. Stacey entitled " Deformation Mechanisms in Magnesium and Magnesium-Aluminium Alloys," which recently appeared in your journal—METALLURGIA, Sept. 1958, **58**, (347), 125.

A great deal of the text has a direct bearing on my own present field of work, and therefore I wondered whether Mr. Stacey could oblige me by appending references to some of the interesting, but unreferenced, observations included in his text, as such references would be of great interest to me. The items I have in mind are as follows :–

(1) " The effect of strain rate is not yet certain," and

(2) " The transition temperature at which the change from brittle to ductile fracture occurs is a function of grain size " (both page 127, column 2, lines 32–34.)

(3) " Due to the enhanced ductility of fine grain material " (page 126, column 1, line 39.)

This latter point, particularly, is not to my knowledge a commonly accepted belief, as fine grained material is usually consistent with higher strength. As strength and ductility are generally inverse functions, this would imply that *inferior* ductility, rather then *enhanced* ductility, would be associated with fine grained material.

May I also draw your attention to a source of confusion in Mr. Stacey's paper ? In the text, Mr. Stacey states that " Grant, Servi and Chaudhuri[9] have studied the effects of grain size on slip and grain boundary sliding in *magnesium* deformed at 260°C." (page 125, column 1, lines 42–44). In the reference list at the conclusion of his paper, however, Mr. Stacey attributes the work to Grant, Servi and *Norton* (Reference 9, page 128). Furthermore, referring to the journal Mr. Stacey associates with reference 9 (*J. Metals*, 1952, **4**, 962), I find that Grant, Servi and Norton, on page 965 report observations on subgrain formation in *aluminium*, but to the best of my knowledge make no mention of *magnesium*. I wonder, therefore, if Mr. Stacey could also clarify this matter, as a reference of the type described in his text (page 125, column 1, lines 42–44) would also be of interest to me.

Yours faithfully,

B. ALLEN.

Department of Industrial Metallurgy,
Birmingham University.
February 1959.

The Editor, METALLURGIA.
Sir,

I fully agree with Mr. Allen's comments about the Reference 9 in the reference list. This is an error, for which I apologise, and for which a correction note is worthwhile. The reference given in the text to N. F. Grant, I. S. Servi and A. Chaudhuri is correct, the source being *J. Metals*, 1953, **5**, (2), 217.

In connection with the relationship between transition temperature and grain size, the reference Mr. Allen requires is that in the very next sentence of text to the one he quotes, viz. Reference 23. The effect of strain rate is also mentioned in the same paper, where it is said that fracture strength is independent of strain rate for $\dot{\epsilon}$ between 0·01% per minute and 100% per minute. I do not think these workers say anything about the effects at lower strain rates, which were of particular interest to me.

On the question of variation of ductility with grain size, I agree with Mr. Allen that in tensile tests fine grain size is associated with increased strength, implying reduced ductility. My interest was in creep strain rates and not in tensile strain rates, and my paper should have emphasised this. Data illustrating the increase in ductility of fine grained compared with coarse grained Magnox A12 under creep conditions have now been published in the open literature. Two creep curves are given in Fig. 16 of T. J. Heal's paper " Magnesium and its Alloys," *Nuclear Engineering*, Feb. 1958, and grain size data is given in the text (mechanical properties section). More extensive data is given in Geneva Conference Paper A/Conf.15/P/305 (2nd U.N. International Conference on The Peaceful Uses of Atomic Energy) by T. J. Heal. This paper shows that the fracture strain of Magnox A12 at 200°C. increases unevenly from about 8% to about 50% as the grain size decreases. At 400°C. there was no clear trend, but the fracture strain was always in excess of 30%. It was at temperatures of 150°–250°C., under creep strain rate conditions, that I proposed the increased ductility obtained with fine grain sizes was responsible for the peak in the elongation-temperature curve, rather than the earlier explanation based on a change in the number of operative slip systems and on the effect of intergranular cavitation.

Yours faithfully,

R. D. STACEY
for Head of Laboratories.

United Kingdom Atomic Energy Authority,
Industrial Group, R. & D. Branch,
Preston.
March 1959.

The Effect of Surface Preparation on the Adhesion of Bearing Metal to Steel

The Editor, METALLURGIA
Sir,

In your March issue, Mr. Thwaites, of Tin Research Institute, describes some experiments showing that the bond obtained between whitemetal and steel depends upon the prior treatment of the steel, acid pickling being superior to shotblasting or grinding. This is in line with the practical experience of the writer's Company. It has always been found that some form of acid etching is necessary to obtain the best results in bonding whitemetal to steel. We have also some experimental work confirming very closely Mr. Thwaites' conclusions. For example, in one series of experiments, a bond strength figure of 14,150 lb./sq. in. was obtained after pickling, but only 10,350 lb./sq. in. after shotblasting. The result obtained after pickling is better than the result after shotblasting at the 1% significance level.

The writer is not entirely convinced, however, that Mr. Thwaites' explanation of this difference is by itself adequate, for the following reasons :—

(*a*) While some loosely adherent steel particles are sometimes pulled away by the whitemetal, it is doubtful whether this represents a sufficient area of bond to account for the difference.

(*b*) In some cases, with unetched steel, the $FeSn_2$ layer appears to separate cleanly from the steel, with no evidence of steel particles adhering to it. This is clearly illustrated in the excellent photomicrograph which Mr. Thwaites shows in his Fig. 5.

(*c*) It has been found by the writer's Company that rolled steel strip, which shows no metallographic evidence of excessive surface deformation, and which appears to tin perfectly, nevertheless gives an inferior bond unless it is given a suitable etching treatment prior to bonding. In this case, bond failure does not appear to be associated with the tearing off of any loose particles of steel.

The writer believes that some more subtle phenomenon is involved here. The extreme surface of cold worked steel appears to possess some characteristic inclining it towards a rather weak bond. One possibility is that when the iron-tin compound forms, the diffusion involved in its formation can result in the condensation of lattice vacancies at the interface by an effect similar to the Kirkendahl effect. On this hypothesis, the effect etching or pickling will be to remove this extreme surfacelayer. It is suggested that this might well justify furthers tudy.

However, the practical conclusion that steel should, if at all practicable, be subjected to carefully designed chemical treatment before whitemetal bonding is certainly accepted.

Yours faithfully,
P. G. FORRESTER,
Chief Metallurgist

The Glacier Metal Co. Ltd.,
Kilmarnock,
March 1959

The Editor, METALLURGIA.
Sir,

I was interested to read Mr. Forrester's letter and pleased to find that our laboratory results were borne out in practice. However, whilst not denying the possibility that condensation of vacancies may occur leading to discontinuities in the bond and hence a lower bond strength, I feel that the original and simpler explanation is more justifiable. In particular, Mr. Forrester's point (*a*), that the loosely adherent particles of steel represent only a small percentage of the total bond surface is true, but I suggest that the bond strength is not merely reduced in proportion to this percentage, but that there may be a " notch " effect resulting from these points of weakness, and the overall reduction in bond strength is thus greatly increased. This suggestion is put forward on page 124 " . . . easily torn from the surface. . . . permitting a tearing stress to be exerted on the $FeSn_2$ layer . . . "

With regard to the reduction in bond strength on heavily cold-rolled strip, that Mr. Forrester has found, a few experiments have been planned at the Tin Research Institute to study the effect of rolling reduction and of steel composition on adhesion.

Yours faithfully,
C. J. THWAITES,
Asst. Chief Metallurgist,

Tin Research Institute,
Greenford, Middlesex.
April 1959

Steel Forging Film

" DROP FORGERS IN STEEL," the latest technical film of English Steel Forge and Engineering Corporation, Ltd. Sheffield, is a continuation of the E.S.C. Group policy of covering individual activities of its subsidiary companies as follow-ups to the first E.S.C. general film, entitled " Engineers in Steel," which was made a few years ago. It begins with a general introduction to the plant used in the drop forging industry, and describes the metallurgical properties which the drop forging process gives to a component, explaining, amongst other properties, the importance of grain flow. In the film a 4-throw crankshaft for a commercial vehicle is shown at all stages of manufacture, beginning with the machining of the die blocks and making of the steel, and ending with finish machining and inspection. Another feature is the whole sequence of forging a large 6-throw crankshaft for a diesel engine.

Other sections of the film deal with the large variety of E.S.C. drop forged components manufactured for the automobile, petroleum and aircraft industries. These sequences include many scenes taken ' on location ' at the works of users of E.S.C. drop forgings. A new electric locomotive is seen in use on British Railways, and some of the film's most interesting shots show the forging under a 2-ton steam hammer of the oleo leg for the Vickers " Valiant " long range bomber.

" Drop Forgers in Steel " is a 16 mm. colour film and takes 35 minutes to show. Produced by the E.S.C. Film Unit under the guidance of the E.S.C. Film Committee it was completed in under a year. The commentator is Kenneth Kendall of the B.B.C. The film will soon be put on general release to educational and industrial organisations, and applications for free loan should be made to the Publicity Manager, English Steel Corporation, Ltd., River Don Works, Sheffield 9.

Instrument Exhibition on Tour

THE Kent mobile-exhibition, now embarked on a nine-week U.K. programme covering a route of over 1,600 miles, is scheduled to stop at approximately 30 different locations. It will be available for inspection by engineers and industrialists between Cardiff, Glasgow and Scunthorpe, and features a selection from the wide range of Kent industrial instruments and controls. This travelling showroom, in the last months of 1958, aroused a great deal of foreign interest during an extensive overseas tour.

The comprehensive range of equipment on view includes the latest Kent electronic developments, such as the Mark 3 Multelec electronic strip-chart indicator/recorder; the Commander KE electronic circular-chart indicator/recorder/controller; and a selection of Kent electronic component assemblies. One of these—the highly-sensitive synchronous converter—is demonstrated by means of a stroboscopic display unit. Also featured are the Commander Kent-Barton mercuryless flow recorder, with Barton patented rupture-proof bellows; Multelec Mark 2 Universal pH recorder, and miniature primary elements available for flow-line and tank; Multelec Mark 2 conductivity indicator/recorder; a range of small pipe-line meters for totalising steam, water and oil flow; the new Kent high-pressure manometer; and examples of Kent pneumatic controlling units. Interesting working models are also on view.

Further details of locations and dates may be obtained from Exhibition Department, George Kent, Ltd., Luton.

NEWS AND ANNOUNCEMENTS

Iron and Steel Institute

Award of Medals and Prizes

The Council of The Iron and Steel Institute has announced the award of the following medals and prizes :

Bessemer Gold Medal for 1959—To Professor Bo Kalling, until recently Director of Research, Stora Kopparbergs Bergslags Aktiebolag, Sweden.

Sir Robert Hadfield Medal for 1959—To Mr. A. Jackson, Technical Adviser on Steelmaking, The United Steel Cos., Ltd.

Andrew Carnegie Silver Medal for 1958—To Dr. P. Vasudevan, Department of Metallurgy, University of Manchester, for a paper on " The Kinetics of Bainite Formation in a Plain Carbon Steel " (*Journal of the Iron and Steel Institute*, 1958, December, p.386) ; his co-authors, Dr. L. W. Graham and Dr. H. J. Axon, were not eligible for an award.

Williams Prize for 1958—To Mr. H. C. Child, Research Manager, William Jessop & Sons, Ltd., for a paper on " Vacuum-Melting of Steels " (*Journal of the Iron and Steel Institute*, 1958, December, p.414) ; his co-author, Mr. G. T. Harris, was not eligible for an award.

The presentations will be made at the Annual General Meeting on May 6th, 1959.

Instrument Exhibition

An exhibition of photometric instruments and microscopes of all types will be held in London from May 11th to May 21st. It will be staged in the showrooms of Degenhardt & Co., Ltd., United Kingdom agents for Carl Zeiss of Western Germany, at 6 Cavendish Square, London, W.1. Throughout the exhibition four technical experts from the Zeiss works at Oberkochen will be in attendance to give advice on the applications of the instruments and the method of employment. At its conclusion in London the exhibition will be moved to Glasgow where it will open at McLellan Galleries on May 26th and continue until May 29th.

Among the most important new instruments to be shown is the P.M.Q. II Spectrophotometer, designed for extremely rapid quantitative and qualitative analyses of compound substances ; the Electrophotometer Elko II, designed for photometric analysis ; a diffusion recorder ; an automatic extinction recorder of electrophoresis paper strips ; and a wide range of microscopes, including two important camera microscopes with built-in automatic exposure measuring devices.

I.B.F. Conference

The 56th Annual Conference of the Institute of British Foundrymen is sponsored this year by the Tees-side Branch, and the technical sessions and social functions will be held in Scarborough. Following a civic reception on the evening of Tuesday, June 9th, the Annual General Meeting will take place on Wednesday morning, June 10th, and will be followed by the Presidential Address of Mr. C. H. Wilson, General Manager and Director of Cochranes (Middlesbro') Foundry, Ltd., and the Edward Williams Lecture on " Thoughts on the Future of the Ironfounding Industry," by Sir Frederick Scopes. Technical sessions have been arranged for Wednesday afternoon and Friday morning and afternoon, Thursday being devoted to a series of whole-day works visits. Social functions include the annual banquet on the Wednesday evening, a theatre evening on Thursday, and a dance, buffet and cabaret, to close the proceedings, on Friday evening.

Welding Conference

The Deutscher Verband für Schweisstechnik e.V. is organising a welding conference to be held in Berlin from June 23rd to 26th, 1959. The theme of the conference will be " Welding Technology for Power Supply " and the papers to be presented are grouped under four main headings : (1) the most important types of reactors, their materials and their welding problems ; (2) special problems in electric power transmission ; (3) welding in pipe construction ; and (4) new developments in the field of large size turbine and generator construction. Further particulars may be obtained from Deutscher Verband für Schweisstechnik e.V., Harkortstrasse 23, Düsseldorf, Germany.

Royal Society Fellowships

The list published last month of scientists newly elected to Fellowship of the Royal Society included the following :—

Mr. G. B. R. Fielden, Director of Research, Ruston and Hornsby, Ltd., Lincoln ; distinguished for his applications of scientific principles to the development and design of industrial gas turbines.

Prof. W. C. Price, Professor of Physics at King's College, University of London ; distinguished for his contributions to chemical physics, especially to spectroscopy.

Prof. G. V. Raynor, Feeney Professor of Physical Metallurgy in the University of Birmingham and Head of the Department of Physical Metallurgy ; distinguished for his research on the structure of metals and alloys.

Dr. R. Spence, C.B., Chief Chemist and Head of the Chemistry Division, Atomic Energy Research Establishment, Harwell ; distinguished for his work on the chemistry of radioactive elements, and for his leadership of the Chemistry Division at Harwell.

Jessop-Saville

The Steel Division of the B.S.A. Group of Companies comprises William Jessop & Sons, Ltd., J. J. Saville & Co., Ltd., and Bromley, Fisher & Turton, Ltd. For the last thirty years, the Jessop and Saville concerns, both makers of special steels, have been under common management, and during this time their particular fields of interest have been developed and merged in complementary directions. It is now considered appropriate for administrative convenience and efficiency that a company known as Jessop-Saville, Ltd., should manufacture and sell the products of the Steel Division, other

than certain small tools, which are produced at a separate works at Portland Street, Sheffield. These small tool products, comprising a wide range of carbide tips and tipped tools and butt welded high speed steel tools will be manufactured and sold by a new company, Jessop-Saville (Small Tools), Ltd. Jessop-Saville, Ltd., and Jessop-Saville (Small Tools), Ltd., will operate as separate, wholly-owned subsidiaries of the Birmingham Small Arms Co., Ltd.

Sir Frederick Scopes to Open Foundry Exhibition

Sir Frederick Scopes, one of the leading figures in Britain's iron and steel industry, will open the Foundry Exhibition at Bingley Hall, Birmingham, on May 21st. The exhibition—first of its kind devoted solely to the foundry industry—will continue until May 30th. Sir Frederick, who is chairman of the Board of Governors of the National Foundry College and a past-president of the Joint Iron Council, was knighted in 1954. Since 1957 he has been chairman of the Stanton Ironworks Co., Ltd., of which he was managing director from 1942 to 1957. He has also been a managing director of Stewarts & Lloyds, Ltd., and holds directorships with a number of companies in the iron and steel industry. Among the offices which Sir Frederick holds is that of chairman of the British Coking Industry Association.

Rubery Owen's Rowen Arc Division

The Rubery Owen Group has formed a RowenArc Division to manufacture under licence in this country a new type of arc-welding equipment, developed by the Westinghouse Electric Corporation of Buffalo, New York, and known in America as West-Ing-Arc. RowenArc utilises a welding gun with a continuous wire electrode, and the use of carbon dioxide and argon gases in place of solid flux eliminates slag, so that one weld can be put on another without cleaning. It also converts arc-welding into a semi-automatic process, by using a continuous electrode wire, whilst still retaining the flexibility of manual monitoring and control.

From a study of the results achieved with the use of the system in the United States and after experimenting with several West-Ing-Arc guns, the Rubery Owen Group believe that considerable production gains could result from its use in this country, and a licence agreement has been concluded to permit them to make the equipment here and sell it under the trade name RowenArc. At the new RowenArc factory at Longford, Coventry, a special laboratory, whose function is "to overcome the impossible in welding," will be put at the disposal of British industry.

Iron and Steel Import Duties

Under the Import Duties (Temporary Exemptions) (No. 1) Order, 1958, the import duties on (*a*) most types of cold-reduced steel sheets of a value of less than £90 per ton, and (*b*) coils for re-rolling, are suspended until June 30th, 1959. After consultation with the Iron and Steel Board about the supply position, Her Majesty's Government have decided to make a new Order prolonging until December 31st, 1959, the suspension of the duties on these sheets and on the coils for re-rolling (up to 4 mm. in thickness). This new Order, the Import Duties (Temporary Exemptions) (No. 4) Order, 1959, (S.I. 1959 No. 522) will come into operation on July 1st, 1959. Copies of the Order may be obtained from Her Majesty's Stationery Office or through any bookseller, price 3d. (by post 5d.).

News in Brief

The Electric Motor Division of Newman Industries, Ltd., has opened an additional Area Office at 59, Grey Street, Newcastle upon Tyne, 1 (telephone Newcastle 2–3970). A stores, adjacent to the new office will carry stocks of electric motors.

Stewarts and Lloyds, Ltd., the steel tube manufacturers, have recently negotiated two contracts with Russia—one for £460,000 worth of boiler and steam tubes and the other for £383,000 worth of oil well tubing for the Russian oil industry. Much of the tonnage involved (5,500 tons for the first contract and 4,100 tons for the second) will be produced at Stewarts and Lloyds' works at Corby.

A new Sub-office of The English Electric Co., Ltd., has been opened at 14 Albert Road, Middlesbrough (telephone Middlesbrough 44346/7).

The Sheffield Wire Rope Co., Ltd., of Darnall, Sheffield, has recently been acquired by the Firth Cleveland Group of Companies. Now the only wire rope making firm in Sheffield, the company has during its fifty years specialised in the manufacture of wire rope for the mining, fishing, marine and general engineering industries.

The London Office of Rocol, Ltd., manufacturers of a wide range of molybdenum disulphide and other specialised lubricants are now at General Buildings, Aldwych, London, W.C.2., telephone Holborn 1985 (two lines).

The address of the Cambridge Branch Office of British Insulated Callender's Cables, Ltd., is now 65, Devonshire Road, Cambridge. The telephone number remains as before: Cambridge 55451/2.

The Federal Government of Nigeria is to sponsor a £500,000 steel rolling mill in Lagos shortly, according to a reliable source in Lagos, says a Barclays Bank D.C.O. message from the area. The project is for the production of reinforced steel rods from domestic ferrous scrap which is at present being exported abroad.

For handling West Northamptonshire iron ore, two rotary drum dryers have been ordered from Buell (1952), Ltd., a subsidiary company of Edgar Allen & Co., Ltd. Each drum measures 9 ft. 2 in. in diameter, is 46 ft. long, and has a capacity of 50 tons of wet ore per hour, sized $2\frac{1}{2}$ in. to 0 in.

An order for a continuous malleablising plant for the production of ferritic and pearlitic blackheart malleable iron castings at a rate of $\frac{1}{2}$-ton/hr. has just been received by Metalectric Furnaces, Ltd., Smethwick, from Gloucester Foundry, Ltd., Gloucester. It will be similar in design to a continuous unit already installed at The Ford Motor Co., Ltd.

Johnson, Matthey & Co., Ltd., have acquired an interest in the important Italian precious metal refining and manufacturing company Metalli Preziosi S.p.A. of Milan. This old-established company, by far the largest enterprise of its kind in Italy, has its head office in Milan and its principal refineries and production centre in the new industrial zone of Paderno Dugnano, near Milan.

RECENT DEVELOPMENTS
MATERIALS : PROCESSES : EQUIPMENT

Bare Wire Welding

EQUIPMENT for CO_2 'bare wire' welding has recently been introduced by Philips Electrical, Ltd. With this process, it is claimed that the mass production of such welded parts as main chassis members, bottled gas cylinders, car wheels, etc., can be considerably speeded-up. Furthermore, welds are protected from hydrogen and nitrogen by an atmosphere of CO_2 costing only a fraction of the price of argon.

Basically, the machine consists of a welding head which carries the wire at the appropriate feed rate and surrounds the arc with an atmosphere of CO_2. A single control lever engages the wire feed and switches on the carriage motor and arc. Water cooling is independent of the mains supplies. The process can be used for welding a very wide range of steels, and labour costs are cut by the resultant faster welding which requires little attention in repeat operations. The welds produced are homogeneous and of deep and even penetration. The arc is self-regulating, and stocks of expensive powders are not required. Nitrogen porosity is virtually eliminated by the low nitrogen and hydrogen content.

Industrial Equipment Division, Philips Electrical, Ltd., Century House, Shaftesbury Avenue, London, W.C.2.

Silver Anodes

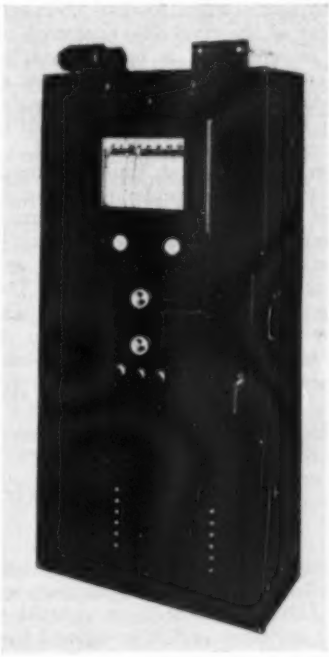
JOHNSON, MATTHEY AND CO., LTD., announce that they have recently investigated the influence that different metallic structures and physical conditions have upon the performance of high-purity silver anodes in silver plating baths. Several important conclusions were reached, and as a result the company has developed a new type of silver anode. Matthey C.A. anodes, because of special processing, have a structure consisting of small equi-axed grains, and are particularly resistant to flaking or shedding in high speed plating baths. Moreover, the anodes show remarkable tolerance to variations in the composition of the electrolyte and in anode current density.

Johnson, Matthey & Co., Ltd., 73–83, *Hatton Garden, London, E.C.*1.

Dewpoint Recorder Controller

THE measurement of dewpoint as a ready estimate of the "carbon potential" of suitable furnace atmospheres is now very widely accepted as the most practical means of controlling such operations as carburising, carbo-nitriding and carbon restoration. Suitable instruments for spot checks are in wide use but continuous recording allied with automatic control of furnace atmosphere requires an instrument with quick response, high accuracy and reliability. The Ipsen Dewtronik, now made available in this country, has been developed to meet this specification.

Approximately 25 cu. ft./hr. of the atmosphere under test is drawn by a specially developed pump through a properly designed sampling and filtering system, supplied with the instrument. The sampled gas passes over the glass insulated face of a bar cooled by a refrigerating system; two platinum electrodes on the exposed glass face are connected to the Dewtector, an electronic device which applies suitable potential to the electrodes and "senses" any moisture film immediately it develops. Formation of "dew" triggers a relay and turns on heaters built into the "sensing head." Dispersion of the dew cuts out the heater and the design is such that in operation the sensing head face is maintained within 2° F. of the true dewpoint of the sample gas.



A thermocouple with junction adjacent to the electrodes signals the prevailing dewpoint temperature to a standard indicating and recording potentiometer. Mercury switches in this instrument act according to the pre-set required atmosphere dew point to operate suitable solenoid valves in additive gas lines or motorised ratio controllers, thereby maintaining furnace or generator atmosphere dewpoint within very close limits. The operating range of 0° F. to 90° F. (or ambient temperature) covers most requirements in this field.

The instrument and accuracy are completely unaffected by all normal atmosphere constituents, *including ammonia*. Reliability rather than economy has been studied in the specification and construction, and only a very little unskilled maintenance is required. The fact that the instrument is functioning correctly can be determined at a glance at any time, due to the rapid cycling action in normal operation. Immediately after loading a batch furnace, very moist atmosphere must

prevail for a short period, and a standard built-in delay timer arranges for the automatic cessation and resumption of sampling to avoid the system being saturated in this brief period.

Built as a compact unit of good appearance, the Dewtronik is available as a single recording controller or dual recording controller. The latter, illustrated above, samples, records and controls two furnaces, two zones of one furnace, or furnace and generator. The speed of response of the instrument makes it possible to supply as further alternatives, either 4-point or 6-point recording instruments.

Ipsen Industries, Inc., 53, *Victoria Road, Surbiton, Surrey.*

Smoke Eliminator

An important contribution towards cleaner air, particularly in so far as the smokeless operation of industrial boiler plant is concerned, is being made by a newly-established engineering concern which is now manufacturing under licence smoke eliminators designed and developed by the Fuel Research Station of the Department of Scientific and Industrial Research.

Apart from ensuring that smoke emitted conforms with statutory obligations under the Clean Air Act, the installation of these new eliminators is claimed to effect substantial savings. Two types are currently available, one for natural-draught hand-fired boilers, and the other for similar boilers with forced draught. The company is also marketing a new smoke density indicator, also developed by the Fuel Research Station of D.S.I.R., which is said to provide a simple, efficient and immediate means of detecting the emission of the prohibited dark smoke.

Lynward Engineering Co., Ltd., 180, *Brompton Road, London, S.W.3.*

Moly-Vapour-Bond

Moly-Vapour-Bond is the trade mark of a British made Aerosol container for spraying molybdenum disulphide. The pressurised 12 oz. containers are fitted with internal agitators and it is claimed that not only does it provide a most convenient, easy and clean method of application, but it produces one of the most effective solid lubricant films so far produced. It finds application in assembly and fitting; as an anti-seize material; for dry lubrication; as a running-in material; for instruments and precision mechanisms; as a safety layer to provide lubrication during temporary breakdowns of a liquid lubricant film; for operation in the temperature range —128° C. to +370° C.; and as a parting agent on dies, die casting machines, etc.

K. S. Paul (Molybdenum Disulphide), Ltd., Great Western Trading Estate, Park Royal Road, London, N.W.10.

Developments in Alkaline Tin Plating

As the result of negotiations with the Metal and Thermit Corporation of New York, Albright and Wilson (Mfg.), Ltd., have announced that they will be the main suppliers of potassium stannate for both immersion plating and electro-tinning in the United Kingdom. The best known application in immersion plating is in the tinning of aluminium pistons. By using potassium stannate instead of, as at present, sodium stannate, it will be possible to achieve substantial reductions of sludge formation together with much improved analytical control limits. Plating baths can be operated continuously and far less time will be spent by operatives in the control and maintenance of the bath.

In electroplating, solutions containing potassium stannate will have a far greater electrical conductivity than a similar solution containing the same concentration of sodium stannate. This means that higher current densities are obtained for a given voltage, so that conditions are ideal for barrel plating. Alternatively a dilute potassium stannate solution can give the same plating rate as a more concentrated one containing sodium stannate, so that wastage by drag-out and initial costs are reduced considerably.

Albright and Wilson have also been licensed by Metal and Thermit to supply "High Speed" tin anodes. One of the main difficulties associated with alkaline electro-tinning lies in maintaining the surface of the tin anode in the correct condition. When operating properly the anode should be coated with a film. If this film is not present it means that the anode is either dissolving too slowly or too fast, and as a result the bath will not operate properly. The most common source of this type of trouble is the lack of room in the electrolyte for sufficient surface area of the anode to keep the bath in balance. The ratio of anode to cathode area must normally be at least one to one, but by using "High Speed" tin anodes, platers will be able to reduce considerably this ratio, and will find it much easier to get the necessary film. An added advantage is that the preliminary high voltage needed to form the film on a normal anode can be dispensed with when using "High Speed" tin anodes. Metals and Methods, Ltd., of Langley, Slough, Bucks, have been appointed sole distributors in the United Kingdom of "High Speed" tin anodes by Albright and Wilson, Ltd.

Purchasers of potassium stannate and "High Speed" tin anodes from Albright and Wilson are conveyed a free licence to operate under British Patents 564,489, 738,018, 596,375.

Metal Finishing Department, Albright & Wilson (Mfg.), Ltd., 1, *Knightsbridge Green, London, S.W.1.*

CURRENT LITERATURE

Book Notices

ALUMINIUM RAINWATER GOODS

No. 13 in the series of Application Brochures published by the Aluminium Development Association, 33, Grosvenor Street, London, W.1., 40 pp., numerous diagrams and illustrations. 10s. 6d.

In this latest of the A.D.A. Applications Brochures, which forms a further item in the series devoted to building subjects, it is noted that aluminium rainwater goods, both wrought and cast, are now established both by the existence of the relevant British Standard and by their approval and use by local authorities and their specification by architects. The brochure opens with a simple statement of the principal factors making aluminium advantageous for this purpose. This is followed by illustrations showing examples of installation on various types of building and including several case histories. The principal section of the book deals with dimensions of the main types of gutters, i.e. half round, ogee and rectangular; also with the associated fittings and accessories. Rainwater pipes and fittings are similarly treated. Notes on the properties of aluminium base materials in this particular service deal principally with strength, low weight and weathering characteristics: there is also a brief account of the behaviour of aluminium in connection with other materials commonly found in building practice. Notes on installation practice cover recommendations for handling on site, on fixing practice, and on painting.

TRANSFORMATION CHARACTERISTICS OF DIRECT-HARDENING NICKEL ALLOY STEELS

Third edition. 92 pp., numerous diagrams and illustrations. The Mond Nickel Co., Ltd., Thames House, Millbank, London, S.W.1.

The first Atlas of Isothermal Transformation Diagrams of Nickel Steels, published in 1950, presented isothermal data for thirteen nickel-containing En steels of commercial manufacture. In 1952, this atlas was revised and extended to include end-quench hardenability data for the same series of steels. The information given in these two earlier editions showed how the results of isothermal transformation studies have assisted in the understanding of steel microstructures, and drew attention to the influence of structure on physical properties. Special heat treatments based on isothermal transformation diagrams were also described, and attention was drawn to limitations inherent in diagrams of this type.

One of the difficulties of applying isothermal data to practical heat treatments, in which a steel is continuously cooled from the austenitising temperature, is that it is not possible to assess reliably from isothermal transformation diagrams the extent and type of transformations which occur during cooling. In view of this difficulty, the book has again been revised, and, in this third edition, amplified to include transformation diagrams for both continuous-cooling and isothermal conditions. The continuous-cooling transformation diagrams, presented in the form considered to be most suitable for practical purposes, cover the range of cooling rates involved in the oil-quenching of 1 in. and 6 in. diameter bars. Both smaller and larger sections are used, and other cooling media are also employed during heat treatment for industrial applications; it is nevertheless believed that the information will prove generally useful in the treatment and application of nickel-containing steels of the types included in the survey.

THE PROPERTIES AND CHARACTERISTICS OF ALUMINIUM CASTING ALLOYS

106 pp. Published by the Association of Light Alloy Refiners and Smelters, 3, Albemarle Street, London, W.1. 4s. 6d.

This is the first publication of this new body, which was formed in June of last year. It contains data for all the aluminium casting alloys to B.S.1490, and in addition to specification requirements, it gives typical properties and information on the physical, foundry, and other characteristics of the alloys, as well as a section on heat treatment and a guide to the selection of alloys. It is based on the original ALAR data sheets, but is published in a more compact form and contains considerably more information.

This smaller edition contains all the data included in the earlier sheets, and additionally devotes a number of pages to nine standard alloys which were omitted from the earlier publication. Revision has also enabled the presentation to be simplified, and much of the earlier duplication of data—unavoidable with separately issued sheets—has been avoided. The booklet is, however, designed so that additional or revised sheets may be added when necessary.

Trade Publications

A new booklet has been produced by John Summers and Sons, Ltd., the sheet steel manufacturers of Shotton, Chester, to illustrate the development and expansion at Hawarden Bridge Steelworks since 1948. The company has spent almost £54,000,000 in the last 10 years, of which £47,439,000 was capital expenditure on plant and machinery. No less than £34,000,000 of this sum was met from the company's own resources. In that time, production of steel ingots rose from 481,500 tons in 1948 to 1,127,000 tons last year. The expansion programme is continuing and by early 1960 it is planned to increase capacity at Shotton to 2,000,000 tons of steel ingots a year, which will involve a further capital expenditure of some £10,000,000. The original works, started in 1893 by the grandfather of the present Chairman, Mr. Richard F. Summers, covered six acres and employed 250 men. Now it employs 11,000 and covers nearly 600 acres.

We have received from Charles Carr, Ltd., Smethwick, a leaflet listing the company's products in the non-ferrous field. These include castings in a range of copper-base alloys produced in normal sand or shell moulds; Monel metal castings for resistance to wear and corrosion; spun cast cored bar in copper-base alloys; chill cast cored or solid phosphor bronze; and non-sparking tools.

During the past few years, The Amber Chemical Co., Ltd., has introduced a number of combustion additives and liquid fuel improvers, designed to bring about increased combustion efficiency, greater boiler availa-

bility, and freedom from problems associated with the burning of all types of industrial fuel. The fuels concerned include residual fuel oil, creosote pitch, bunker fuel, diesel and gas oil, and coal and pulverised fuel. Amber Chemical have recently issued a set of data sheets on their products in this field, giving characteristics, applications and treatment cost. Copies may be obtained from 11A Albermarle Street, London, W.1.

DESCRIBED as an essential to efficient cathodic protection, the Guardion corrosion voltmeter is featured in a new leaflet issued by the Cathodic Protection Division of F. A. Hughes and Co., Ltd. Apart from its use in connection with the checking and maintenance of cathodic protection systems, its design is such as to make it extremely useful for a variety of other purposes where scientific accuracy is required in the field. Ancillaries such as miniaturised half-cell electrodes have been specially produced in conjunction with the instrument, and it has been suggested that it will fulfil a useful function as a measuring instrument for various transistor applications.

A.E.W., LTD., have issued a leaflet describing their new range of electric furnaces for laboratory and workshop use. To prevent heat losses, the drop-down door—which forms a loading platform when open—is efficiently heat sealed, and the chamber has high grade insulation on all sides. The chamber sizes range from $6 \times 2 \times 6$ in. deep to $6 \times 6 \times 12$ in. deep, the larger units being provided with a built-in control panel and pilot lights. The maximum working temperature is 1,000° C., with an optional 1,250° C. model in the larger sizes.

DESPITE the newer techniques used for specialised applications, the vast bulk of welding is today carried out by the metal arc process. Since this was introduced there have been many important developments, one of which, the incorporation of iron powder in the electrode coatings, is discussed in a 142 page book, published by Höganäs-Billesholms A. B., Sweden. It contains two articles, the first, based on European practice, deals with the influence of iron powder upon the weld deposit and the performance of iron powder electrodes during welding. The second is a report of the proceedings, including discussion, at a meeting held in London last year when Mr. D. L. Mathias presented three lectures. The first deals with the production of welding electrodes in the U.S.A.; the second presents a comparison of the fundamental characteristics of iron powder electrodes and conventional electrodes, followed by some practical and theoretical considerations on iron powder properties; and in the third the practical applications of iron powder electrodes are discussed. Copies may be obtained from F. W. Berk & Co., Ltd., Berk House, Portman Square, London, W.1.

ELCONTROL, LTD., have just issued a revised data sheet TR, issue 2, describing their range of standard electronic process timers, cyclic timers and delay switches. The descriptions of the three types of timers have been simplified, and information regarding their characteristics is presented in tabular form, so as to make it easier for users to assess their exact requirements. Attention is drawn to Elcontrol's interest in producing complete sequence control panels to meet specific requirements.

A NEW data sheet gives a useful summary of the physical properties of glycerine including short tables showing specific gravity, freezing points and vapour pressure/relative humidity data for different concentrations of glycerine in water. The data sheet also describes the three principal grades of refined glycerine, namely, the chemically pure, technical and dynamite grades. Printed on heavy board to make it a durable reference, the brochure is available on request to The Secretary, The United Kingdom Glycerine Producers Association, Ltd., 5 Bridewell Place, London, E.C.4.

THE Alloy Division of Union Carbide, Ltd., 103 Mount Street, London, W.1., now has available a revised edition of its Literature List, which had its first printing in April of last year. The new edition titles and describes 85 different publications which are sub-divided into: (1) Ferro Alloys and Metals; (2) Steel Production; (3) Stainless Steel Properties and Uses; (4) Cast Iron; (5) Titanium; and (6) Miscellaneous. Many of the publications listed are original works and, as such, of more than common interest to the many chemists and managers working in the metallurgical and engineering fields. All the booklets listed are available free of charge upon application to the above address.

WE have received from the English Electric Co. Ltd., four new publications. SG/251 (issued by the Switchgear Department, Stafford), is a six-colour, 28-page publication describing frame 'g' air-blast circuit-breakers covering a voltage range of 110 kV. to 165 kV., maximum breaking capacity being 5,000 MVA. A standard interrupter is used throughout the range, and thousands of these units are in use in English Electric outdoor air-blast circuit-breakers all over the world. Various installations as well as breaker components are illustrated. The 40-page publication ST/117 describes English Electric non-reheat steam turbines of 10 MW. rating and above. Many sectional arrangement drawings are reproduced of complete turbines and components. Details of manufacture are illustrated together with installations varying from 10 MW. to 100 MW. units. This booklet is issued by the Steam Turbine Division, Rugby. Geared steam turbo-generating sets of the condenser type, with outputs from 750 kW. to 5,000 kW. are described in a 12-page publication, ST/121, issued by the Small Steam Turbine Department, Whetstone, nr. Leicester. These units are intended for industrial power stations and marine applications. WA/141 is a four page leaflet dealing with the English Electric Hermees electrode for faster welding of heavy sections and restrained joints in mild steel, medium high tensile and carbon and alloy steel, and emanates from the Welding Electrode Division, Clayton-le-Moors, Accrington.

Books Received

"Modern Foundry Practice." Third Edition. Edited by E. D. Howard. 464 pp. inc. index and numerous illustrations. London, 1959. Odhams Press, Ltd. 30s. net.

"Jahrbuch der Schleif-und Poliertechnik und der Oberflächenbehandlung," 1959. 512 pp. Essen, 1959. Vulkan-Verlag Dr. W. Classen. DM 14.

"*The Engineer* Buyers' Guide, 1959." 958 pp. London, 1959. *The Engineer*, 28 Essex Street, London, W.C.2. 7s. 6d. By post 9s. 3d.

"The Geology of Uranium." Translated from Russian by V. G. Urana. 128 pp. New York and London, 1958. Consultants Bureau, Inc., and Chapman and Hall, Ltd. 48s. net.

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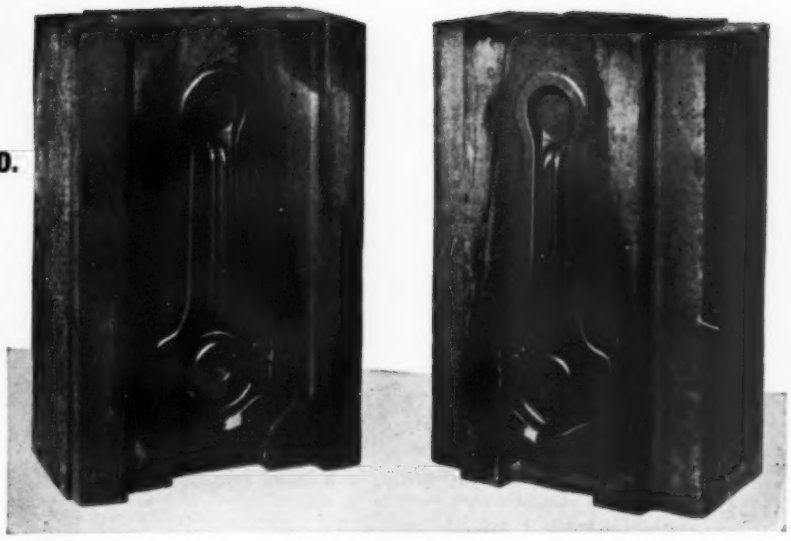

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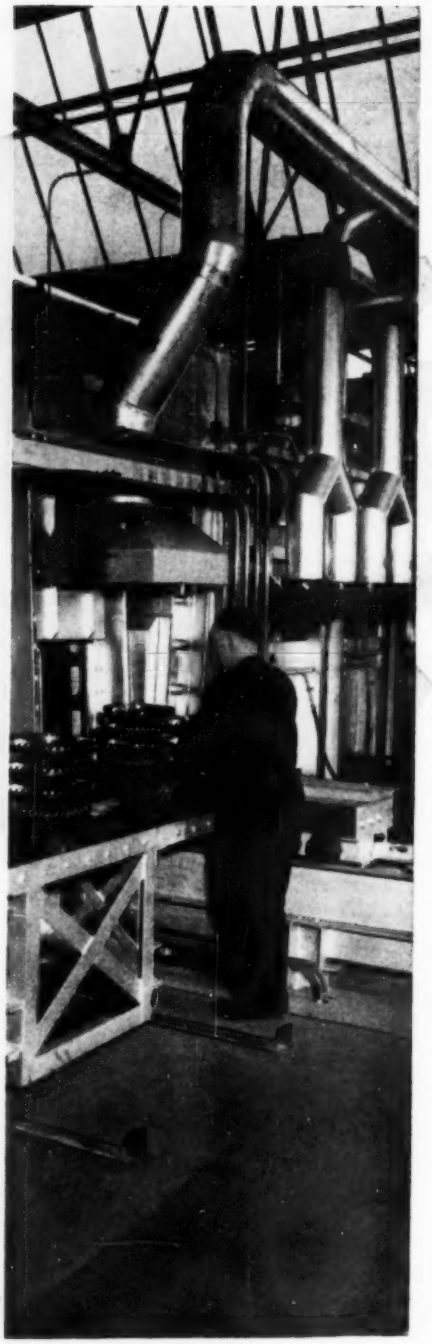
wisdom teeth...



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LABORATORY METHODS
MECHANICAL · CHEMICAL · PHYSICAL · METALLOGRAPHIC
INSTRUMENTS AND MATERIALS
MAY, 1959 Vol. LIX, No. 355

Some Aspects of Potentiometric Titrations in Alloy Analysis

By Duncan R. W. McLaren, A.H.W.C.

Bragg Laboratory, Naval Ordnance Inspection Establishment, Sheffield

Potentiometric titrations are mainly used to follow the course of those reactions which do not lend themselves to colour change indicator methods. Oxidation-reduction reactions—the type most frequently met—are considered with reference to cells using a reference calomel electrode and those using polarised platinum electrodes.

IN the current text-books on analytical chemistry the sections on volumetric analysis by potentiometric or electrometric titration appear to take little cognisance of researches since 1939. This article is intended to discuss oxidation-reduction reactions, which are the type most frequently encountered. They are considered with reference to: (*a*) cells using a reference calomel electrode; and (*b*) cells using polarised platinum electrodes.

Potentiometric titrations are mostly used to follow the progress of those reactions which do not lend themselves to colour change indicator methods. An example of this is the determination of manganese with potassium permanganate in a sodium pyrophosphate medium.[3] The manganous ion is oxidised to the manganic state, in the process of which the permanganate is reduced to form manganic pyrophosphate, which gives a dark red solution.

Cells Using a Standard Reference Electrode

In potentiometric titrations the solution being titrated is incorporated in an electrolytic cell. All cells may be considered to be made up of two half cells. For instance, the Daniell cell consists of the two half cells: (1) metallic zinc in zinc sulphate solution; and (2) metallic copper in copper sulphate solution; connected by dilute sulphuric acid through a porous membrane, usually expressed:—

$$Zn/ZnSO_4 \text{ soln.} : CuSO_4 \text{ soln.}/Cu$$

Thus, when a standard half cell such as a standard calomel electrode (S.C.E.) is connected to the solution to be titrated by a salt bridge to eliminate transference, the cell is completed by having an indicator electrode, such as a platinum electrode.

This cell, when incorporated in a circuit, will record an E.M.F. which can either be balanced against the standard cell, using a galvanometer, or measured directly on a millivoltmeter. This is the basis of all apparatus used in potentiometric titrations. Many metals may be used as indicator electrode, but this article deals only with the platinum electrode.

Titrations controlled by instrumentation, e.g. amperometric, coulometric and potentiometric, rely on variations in the E.M.F. or the conductivity of the cell, due to a change in voltage being measured during the titration. This is greatest at the end-point.

An interpretation of potentiometric titrations was developed by Reilley *et al.*,[1,2] whereby current, voltage and the percentage oxidised state of an ion are combined in a three-dimensional diagram. This is exemplified in Fig. 1, where the dotted line plots the results of a potentiometric titration conducted at constant current. Fig. 2 illustrates the same results graphed normally.

The above, however, represents only one half of a reaction, such as—

$$Fe^{++} = Fe^{+++} + e$$

To obtain a complete reaction of the type

$$Fe^{++} + Ce^{++++} = Fe^{+++} + Ce^{+++}$$

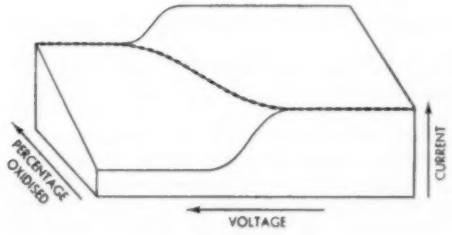

Fig. 1. (left)—Three-dimensional interpretation of a half-cell reaction.

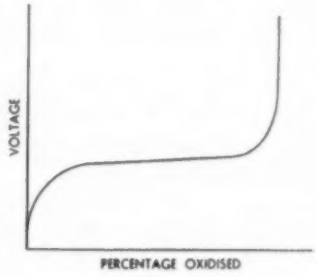

Fig. 2. (right)—The same result graphed normally.

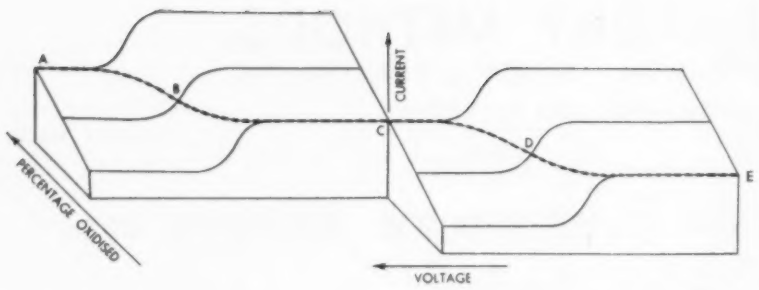

Fig. 3.—Three-dimensional interpretation of a redox potentiometric titration.

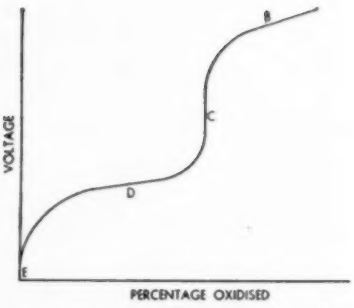

Fig. 4.—The same result graphed normally.

it is necessary to place two of these together to give a three-dimensional diagram of the reaction (Fig. 3). This, when considered on a constant current level, gives a complete curve for a potentiometric titration (Fig. 4), i.e. the path traced out by the dotted line *A B C D E* in Fig. 3. *E D C* represents the Fe^{+++}/Fe^{++} half of the graph and *C B A* represents the Ce^{++++}/Ce^{+++} half.

Since the potential of the S.C.E. is a constant, the change in potential of the cell is due to the change in concentration impressed on the platinum electrode. Thus, at *E* in Fig. 3 the iron is 100% ferrous ion, and on being slowly oxidised to the ferric state the voltage changes as indicated by the line *E D C* until, at the position *C* all the iron is present as ferric ions and cerium as cerous ions. On adding a slight excess of ceric ions the voltage changes as shown by *C B A* in the same figure. It should be noted that if the volume of cerium added after the end-point at *C* is doubled, then the potential reading will be that of *B*, since only 50% of the cerium present is present as ceric ions. It would thus take a very large volume of Ce^{++++} to complete the graph *C B A*.

The theory which controls these half cells is simple. The value of the standard calomel electrode is constant at

$$E_{(red)} = 0{\cdot}2415 - 0{\cdot}00076\ (t - 25)$$

where t is temperature in ° C., and this value is added to the oxidation potential of the titration reaction. In general, if M represents an element or ion

$$\text{then } M = M^{+} + e$$

because

Reduced State = Oxidised State + 1 electron

and oxidation potential

$$E = E_0 - \frac{RT}{nF} \ln \frac{a_{M^+}}{a_M}$$

where a represents the activity of that state. The activity of weak solutions equals the concentration: the latter term is more convenient and is indicated by [ ]; thus,

$$E = E_0 - \frac{RT}{nF} \ln \frac{[M^+]}{[M]}$$

The activity of a solid, or a gas at one atmosphere = 1. In general, for the reaction

$$AB + CD = AD + BC$$

$$E = E_0 - \frac{RT}{nF} \ln \frac{[AD]\,[BC]}{[AB]\,[CD]}$$

The rearrangement may be in the oxidised state of the ions, as in redox reactions, or in the ion pairs of precipitation and neutralisation reactions, e.g.

$$Fe^{++} + Ce^{++++} = Fe^{+++} + Ce^{+++}$$

E_0' = standard oxidation potential of iron

E_0'' = standard oxidation potential of cerium

Before the end-point, $[Ce^{++++}] = 0$ and the potential is governed by the ratio of ferric to ferrous ions, i.e.

$$E = E_0' - \frac{RT}{nF} \ln \frac{[Fe^{+++}]}{[Fe^{++}]}$$

At the end-point

$$\log E = \frac{E_0'' - E_0'}{2 \times 0{\cdot}059}$$

After the end-point $[Fe^{++}] = 0$ and the potential is governed by the ratio of cerous to ceric ions,

$$E = E_0 - \frac{RT}{nF} \ln \frac{[Ce^{+++}]}{[Ce^{++++}]}$$

Two good examples of this type of reaction which may be mentioned here are :—

(1) The determination of manganese by the method referred to earlier. The only interferences to the reaction are the oxides of nitrogen, removed by the fuming with sulphuric acid, and large amounts of magnesium, cadmium and aluminium, which may form precipitates and give low results due to co-precipitation.

(2) The determination of cobalt with potassium ferrocyanide. The reduction of the cobalt occurs in a concentrated ammoniacal citrate medium. Manganese interferes quantitatively and can be allowed for.

Cells Using Polarised Platinum Electrodes

An electrode is polarised when it adopts a potential impressed upon it with little or no change in current; it is ideally depolarised when, upon the passage of current, the potential does not deviate from its reversible value.[8]

It was found by Willard and Fenwick[4, 5] that when two dissimilar metals were used as electrodes during a potentiometric titration a potential difference was recorded. This difference, using for example the palladium-platinum electrodes, was high at first but near the end-point dropped to almost zero. At the end-point an abrupt and characteristic break in the graph was obtained. A bimetallic system may be

created by using platinum electrodes and passing a continuous polarising current of about 30 μA., operating at approximately 0·5 V.

Willard and Fenwick[3-5] made a general study of metal electrodes, and came to the conclusion that many dissimilar pairs of metals, when acting as electrodes, indicate the end-point. They found, however, that the sharpest end-point and greatest deflection was obtained by using polarised platinum electrodes. They made the electrodes from the same piece of platinum and used an anodic polarising current.

Of the theories advanced to explain the potential between the ions of an oxidising agent and an unattackable electrode, Willard and Fenwick support that of Nernst. The latter postulated that the potential is due to an oxygen charge, and in the case of a reducing agent to a hydrogen charge, on the electrode. This is in agreement with the Ionic Theory and Faraday's Law. The platinum functions as a gas electrode.

Thus, assuming that an unattackable electrode may form a solution with a gas, the expression for the development of a single electrode potential, E, may be written :—

$$E = E_0 - \frac{RT}{2F} \ln \frac{[H^+]^2}{[H_2]}$$

$$E = E_0 - \frac{RT}{4F} \ln \frac{[O_2]}{[O^{--}]^2}$$

It should be noted that a specific hydrogen charge corresponds to a specific oxygen charge, and E will increase with rising concentration of hydrogen ion. Increase in hydrogen ion concentration means a decrease in the oxygen ion concentration and an increase in the ratio $[O_2]/[O^{--}]^2$. This also gives an increase in E. Thus, the potential of an oxidising agent will increase with increase in acid concentration; the opposite is the case with a reducing agent. The change of potential depends on the difference in the value of E on either side of the end-point. This will be increased by the addition of acid.

An anodic polarising current will impress on the electrode a higher oxygen charge when the electrodes are immersed in an oxidising solution such as potassium permanganate. At the low voltage used, 0·5 V., the decomposition of the permanganate electrolyte is very slight, and the osmotic pressure of any ions present is not altered.

The relative change in the solution pressure of the absorbed oxygen is increased considerably, causing an increase in the potential between unattackable electrode and solution. As would be expected, cathodic polarisation causes a decrease in the value of the end-point deflection.

The equation which governs potentiometric titrations is

$$E = E_0 - \frac{RT}{nF} \ln \frac{f_{oxid} \quad x}{f_{red} \quad (1-x)}$$

where x is a fraction of the total concentration in the oxidised state. The shape of the graph obtained using polarised platinum electrodes may be obtained by differentiating the above equation with respect to x

$$\frac{dE}{dx} = \frac{RT}{nF} \left(\frac{1}{x} - \frac{1}{1-x} \right)$$

Since dx is the increment of titrant added, by keeping it constant at, say 0·1 ml., then the end-point is that value of x at which dx produces the greatest change in dE.

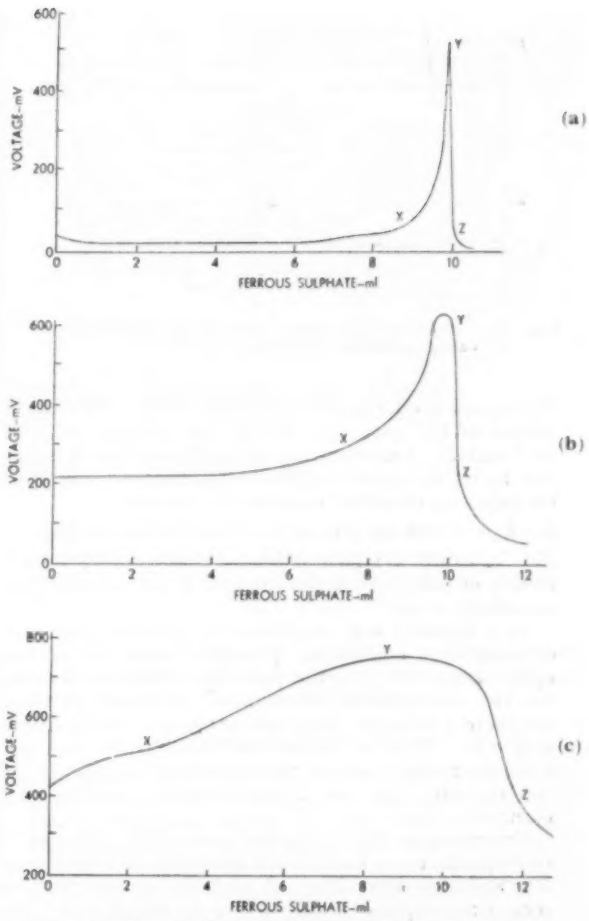

Fig. 5.—Graphs obtained by the potentiometric titration of ceric sulphate solution with ferrous sulphate solution at concentrations of (a) N/10, (b) N/100, (c) N/1,000.

The controlling factor in these titrations is the concentration of x. This is illustrated in Fig. 5, when ceric ion is titrated with ferrous ion in M sulphuric acid. The change in the quality of the end-point is explained after consideration of the implications of concentration limit and electroactivity of the ions.

Ions are considered electroactive if their polarisation curve can be determined, as can be done in the case of Fe^{+++}, Ce^{++++}, SO_3^{--}, etc. They are non-electroactive if their polarisation curve cannot be determined, e.g. $S_2O_6^{--}$, Cr^{++}, Mn^{++}, etc. They are non-electroactive since, at the potentials required, water would be reduced first in the case of oxidants such as $S_4O_6^{--}$, or would be oxidised first as in the case of reductors such as Cr^{++}.

Only the electroactive ions control the value of the potential of the cell. The concentration limit is the limit below which an electroactive ion becomes non-electroactive. For instance, when ferric and ferrous ions are both present in ionic concentrations greater than 10^{-5}, the redox potential is given by the formula.

$$E = E_0 - \frac{RT}{nF} \ln \frac{[Fe^{+++}]}{[Fe^{++}]} = 0{\cdot}735 - 0{\cdot}059 \log \frac{[Fe^{+++}]}{[Fe^{++}]}$$

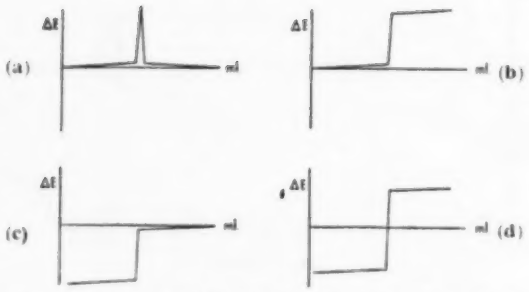

Fig. 6.—Theoretical graphs obtained from titrations using polarised platinum electrodes.

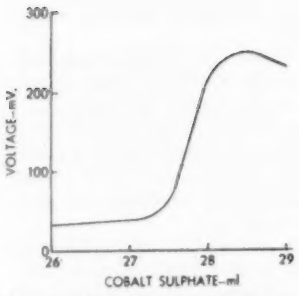

Fig. 7.—Titration of potassium ferricyanide solution with N/100 cobalt sulphate solution.

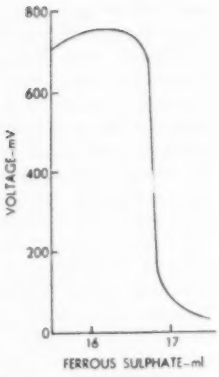

Fig. 8.—Titration of potassium dichromate solution with N/10 ferrous sulphate solution.

This is called equilibrium potential. When the concentration of the ferric ion exceeds the limiting value of 10^{-5} and the concentration of the ferrous ion is below this limit, the latter may be considered constant and the following empirical equation is observed

$$E = E_1 - 0{\cdot}058 \log [Fe^{+++}] = 1{\cdot}0 - 0{\cdot}058 \log [Fe^{+++}]$$

This is called a mixed potential. When the concentration of both ions is less than 10^{-5}, the potential has no definite value.

In a titration cell controlled by polarised platinum electrodes, an equilibrium potential results in a value approaching zero, i.e. the potential difference between the two electrodes is almost zero. A mixed potential results in a potential difference of three or four hundred millivolts. This is because the electroactive ions are diffusing faster to one of the electrodes than the ions of the opposite sign are being attracted to the other electrode.

Returning to Fig. 5, the first part of the curve to X corresponds to an equilibrium potential between cerous ions and ceric ions. From X to Y the concentration of ceric ions decreases until at Y only cerous and ferric ions are present, resulting in a mixed potential. From Y to Z the concentration of ferrous ions increases.

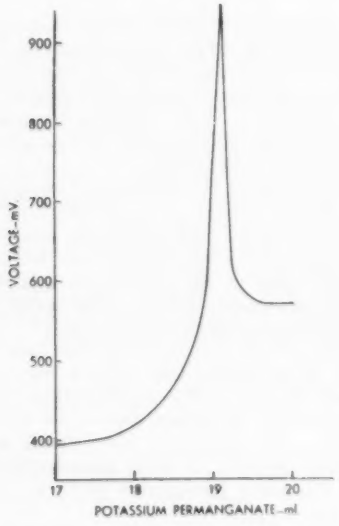

Fig. 9.—Titration of manganous sulphate with N/10 potassium permanganate solution.

Curves (*b*) and (*c*) in Fig. 5 show the effect of lowering the concentrations to a tenth and a hundredth, respectively. From the change in the form of the curves (*a*), (*b*) and (*c*), it will be apparent that there is a minimum concentration below which the end-point cannot be accurately determined.

Coursier[6, 7] studied the curves obtained from titrations using polarised electrodes. He grouped them into four classes, viz :

(1) reduced and oxidised states of the reactants are electroactive,

(2) titrating solution has only one electroactive state,

(3) titrated solution has only one electroactive state,

(4) both reactants have only one electroactive state,

which are discussed below with examples of their occurence in alloy analysis. In all cases the reactant in excess, whether this be the titrating or titrated solution, controls the potential reading.

(1) *Reduced and Oxidised States of the Reactants are Electroactive.*

Fig. 6*a* shows the type of graph obtained. On either side of the end-point a zero reading is obtained by depolarisation due to the equilibrium potential. At the end-point all the titrated solution is oxidised and all the titrating solution is reduced, i.e. both exist in only one electroactive state which does not depolarise the electrodes. A sharp positive or negative potential is indicated which is a function of the nature of the reactants. Fig. 5 illustrates a good example of this type of reaction.

(2) *Titrating Solution has only One Electroactive State.*

Fig. 6*b* indicates the case where the titrated solution gives an equilibrium potential which depolarises the electrodes. The titrating solution gives a mixed potential. The end-point is taken half way along the deflection obtained at the transition point of the two states. An example of this graph is shown in Fig. 7, where potassium ferricyanide is the titrated solution and cobalt sulphate is the titrating solution.

(3) *Titrated Solution has only One Electroactive State.*

This is the reverse of (2), as indicated in Fig. 6*c*. An example is illustrated in Fig. 8, in which potassium dichromate is titrated with ferrous sulphate.

(4) *Both Solutions have only One Electroactive State.*

As shown in Fig. 6*d*, the potential between the electrodes is never zero ; it passes through a maximum or minimum at the end-point, due to the absence of electroactive particles in the solution. An example of this is shown in Fig. 9, where manganese ions are titrated with permanganate ions in a pyrophosphate medium to form an inactive manganic pyrophosphate complex. When the manganous ions are in excess the potential is 380 mV., and when the permanganic ions are present in excess the potential is 570 mV.

Acknowledgment

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Exhibits of Metallurgical Interest at the Physical Society's Exhibition

The exhibits at the Physical Society's annual exhibition of scientific instruments usually include a number of interest to workers in the metallurgical field. This year was no exception, and in this issue we continue a short series of reviews in which such items will be described.

THE B.N.F. thermo-electric metal sorter shown by Nash & Thompson, Ltd., has been developed from the B.N.F. coating thickness meter, and may be used to differentiate between various metals either in the rough rod, bar or sheet form, or in the finished machined condition. It consists of two parts : (1) a probe sensing unit ; and (2) an amplifying indicating unit. The probe unit contains a hot and cold junction, the former, which is a spring-loaded copper heater block with an electroplated hemispherical tip, being housed in a cylindrical Tufnol body. The cold junction is an insulated crocodile clip which must be attached either to the component under test, or to a base plate on which the component is resting.

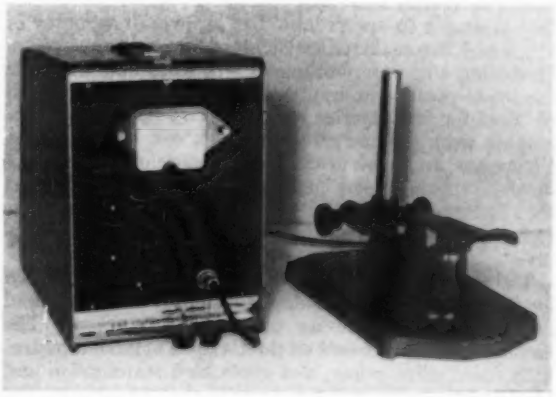
The indicating unit incorporates a chopper-type D.C. amplifier with backing-off and gain controls, which is connected to a 4 in. rectangular moving coil meter via a polarity reversing switch. When the hot tip, which operates at approximately 130° C., is applied to the surface of a metal, a thermo-electric e.m.f. is generated, which in turn is applied to the amplifier via the hot and cold junctions. For a given temperature and tip material different metals will generate their particular voltages, which will differ in a similar manner to the thermo-electric table. These voltages may be amplified over a considerable range using the gain (sensitivity) control, and adjusted to read on any part of the meter scale by using the backing-off (zero) control.

In the present model there are two probes, with their associated control circuits, one tipped with 0·005 in. nickel, the other with 0·015 in. chromium ; both employ barretters in the heater circuits to maintain a constant heat input. Locked and engraved sensitivity and zero controls can be fitted where a restricted range of metals is to be sorted. This enables unskilled personnel to use the instrument on production testing, without any unauthorised adjustment of the controls. This modification has been successfully used for nimonic and nickel alloys, stainless steels, carbon and alloy steels, and a range of non-ferrous metals.

A further development in hand is a probe having interchangeable tips, so that the optimum material may be used in difficult cases of differentiation.

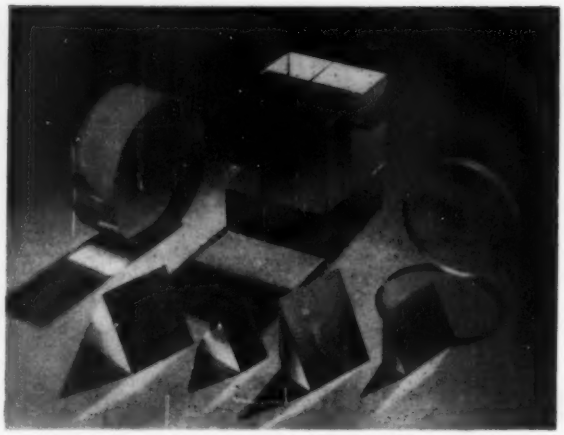
Synthetic Fused Silica

Synthetic fused silica is now recognised to be the purest form of silica available in the world, and in the case of Spectrosil, shown by The Thermal Syndicate, Ltd., the level of impurities is so small that precise analytical methods for many elements are as yet impossible. Direct and indirect analyses for aluminium, boron, calcium, magnesium, iron, copper, manganese, potassium and sodium show that the total impurity content is less than one part per million. This exceptionally high purity of the material makes it eminently suitable for all applications in which the slightest contamination must be avoided, as for example in semi-conductor work. Crucibles of Spectrosil are being used with outstanding



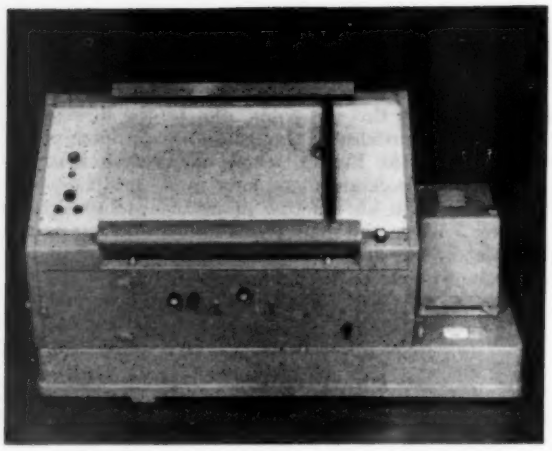
Courtesy of Nash & Thompson, Ltd.

The B.N.F. thermo-electric metal sorter.



Courtesy of The Thermal Syndicate, Ltd.

A selection of optical components in Spectrosil fused silica.



Courtesy of Hilger & Watts, Ltd.

The Ultrascan recording spectrophotometer.

success in growing single crystals of silicon from the melt for the production of silicon transistor devices.

The optical properties of Spectrosil are unique. There is practically no absorption at wavelengths above 2,000 Å; and even at 1,700 Å the transmission per cm. is 75%. In addition, no visible or ultra-violet fluorescence can be detected on exposure to the 2,537 Å mercury resonance line. These advantages are being utilised by Messrs. Hilger & Watts, Ltd., who have recently introduced Spectrosil prisms in their Uvispek spectrophotometers. At present, the material is not suitable for use in the infra-red, since it absorbs strongly at 2·7μ. Up to dosages so far given ($4{\cdot}5 \times 10^8$ Roentgens), no visible coloration has been produced by gamma rays or by pile irradiation, making the material particularly suitable for all types of radiation work.

It is claimed that Spectrosil is the only fused silica to be completely homogeneous and free from grain structure. It is available as block material for lenses, prisms, plates, windows and discs; as rod, fibre, and wool; and as hollow ware, such as tubing, boats, crucibles and special apparatus.

Recording Spectrophotometer

The H999 Ultrascan, exhibited in prototype form by Hilger & Watts, Ltd., is a recording spectrophotometer that is simple to operate and has an overall accuracy of 1%, which is considered satisfactory for routine purposes. Producing a spectrophotometer within these limitations has made possible an appreciable saving in cost. It will be ideal for laboratories where a good deal of spectrographic work is done; routine work can be left to the Ultrascans, and work needing great precision or the use of special accessories can be done with the Uvispek. Thus the advantage is twofold: needless expenditure is saved; and, by using a recording instrument, much time is saved.

The range of the instrument, 2,000–7,500Å, is decided by the sensitivity of the detecting photomultiplier, and not by the tranmissivity of the silicon prism. The monochromator is based on the Uvispek monochromator, with fused silica prism, and gives high tranmission and remarkable freedom from stray light throughout the complete range. There are two light sources—hydrogen discharge U.V. source and tungsten filament visible source—and the changeover of sources is automatic at the point in the spectrum at which the energy curves of the lamps intersect.

Three speeds are available, giving complete scan times of 4, 8 or 16 minutes, and are selected by manual adjustment of gear wheels. The scan can be limited, by preset switches, to any chosen region of the spectrum. In the new design of flat-bed recorder, the pen automatically returns to the beginning of the scan in preparation for the next test. The two standard sizes of chart (23×11 in. and $13\frac{1}{4} \times 8$ in.) are calibrated in wavelengths and also ruled linearly in frequency. Two ordinate scales are available, linear in transmission or density, and change from one to the other is achieved by replacement of cams. Controls are provided allowing ordinate scale expansion so that full scale movement of the pen can be obtained over the transmission range 0–10%.

Whilst the production model will be similar in most respects to the prototype, it will be lower and will have a somewhat more streamlined appearance. Instead of a forward-looking aperture to the cell compartment, there will be accessibility to this compartment by both overhead and forward-opening covers. The development and availability of accessories will be subject to demand, but those that are being, or are to be, made available include (*a*) an attachment to allow automatic rescanning of the spectrum, (*b*) a flow-through cell, and (*c*) provision for a "dry box" for radioactive samples.

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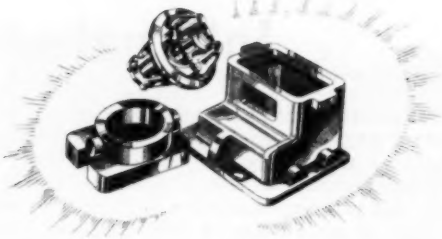

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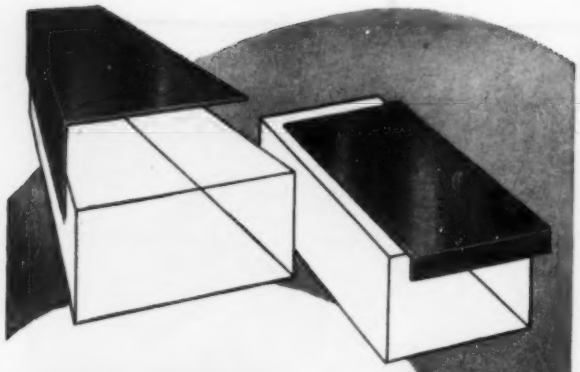

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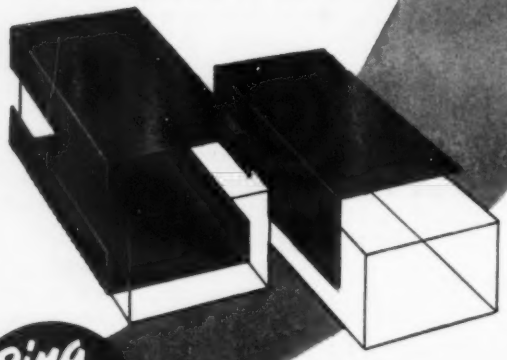

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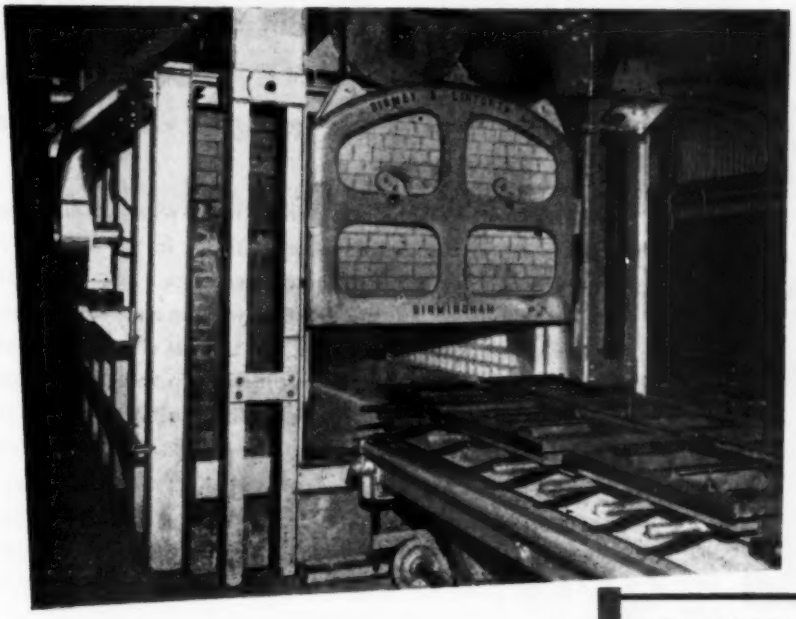

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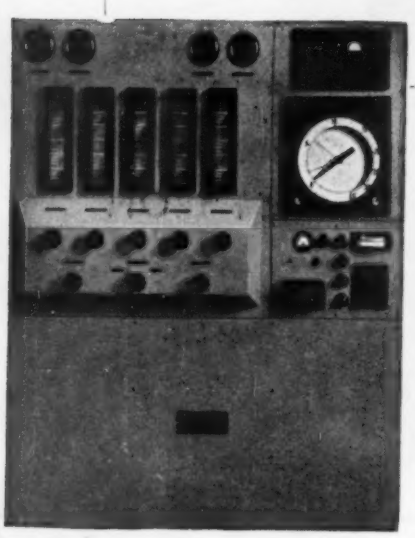

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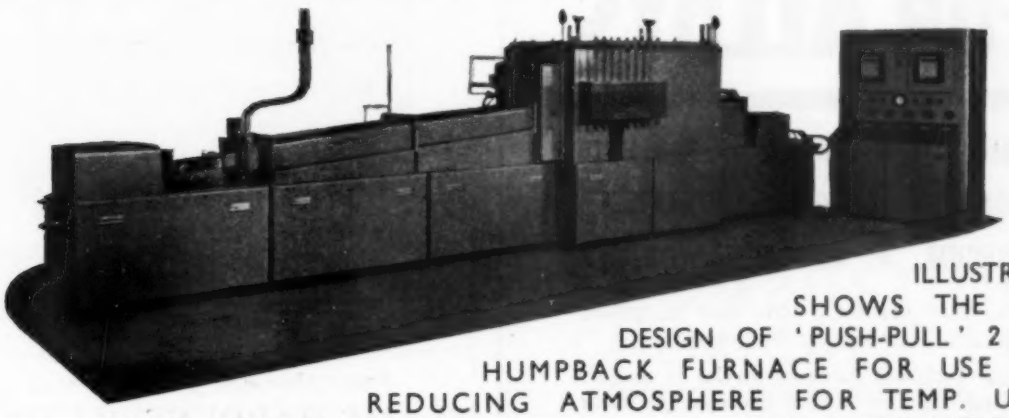

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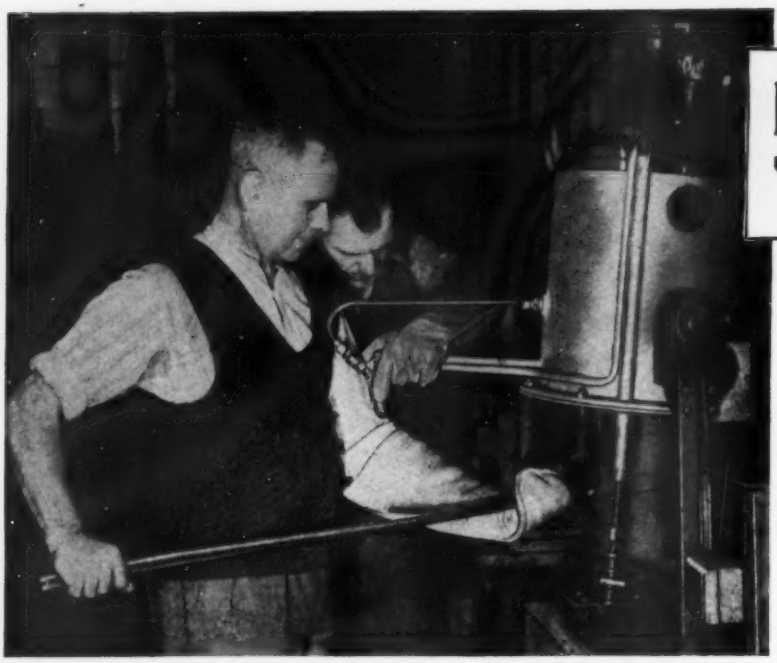

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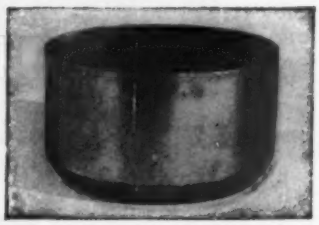

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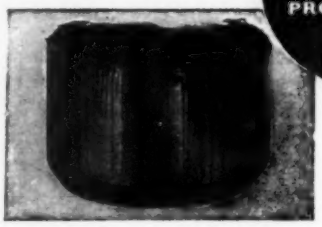

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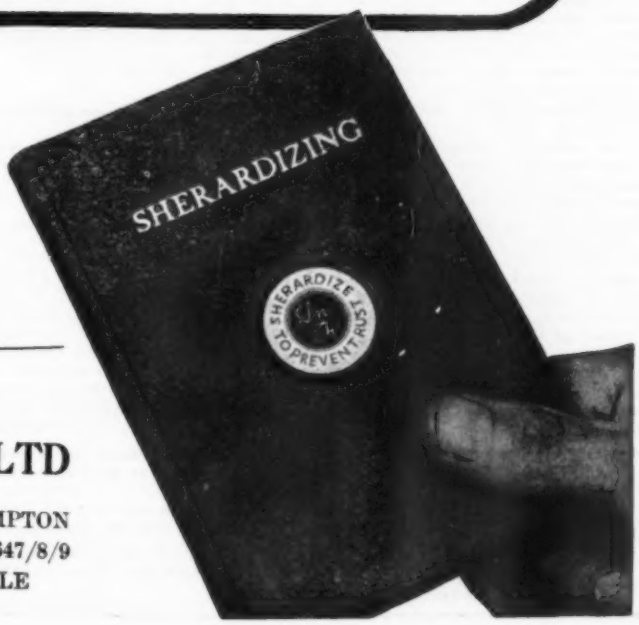

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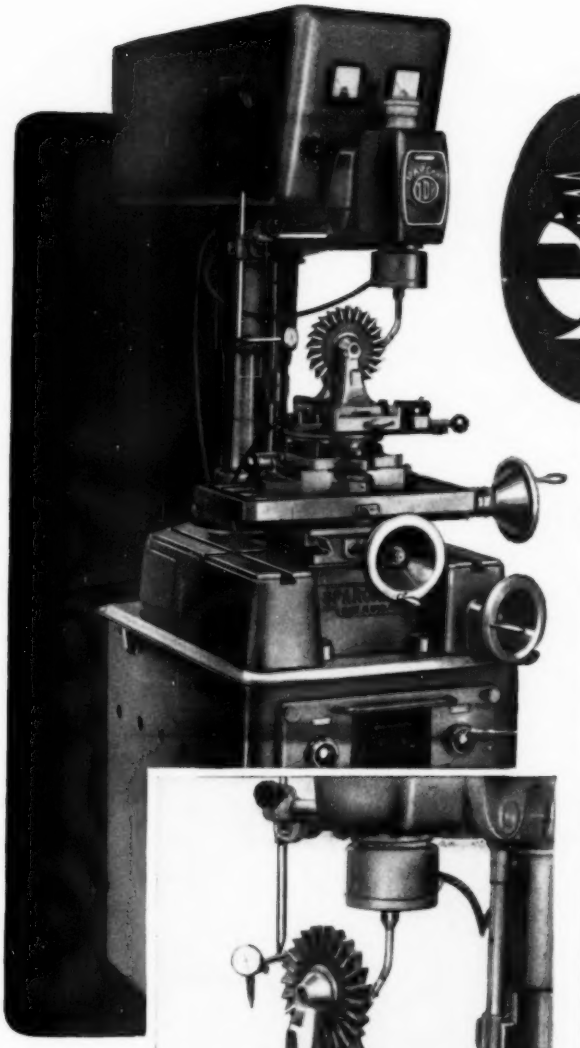
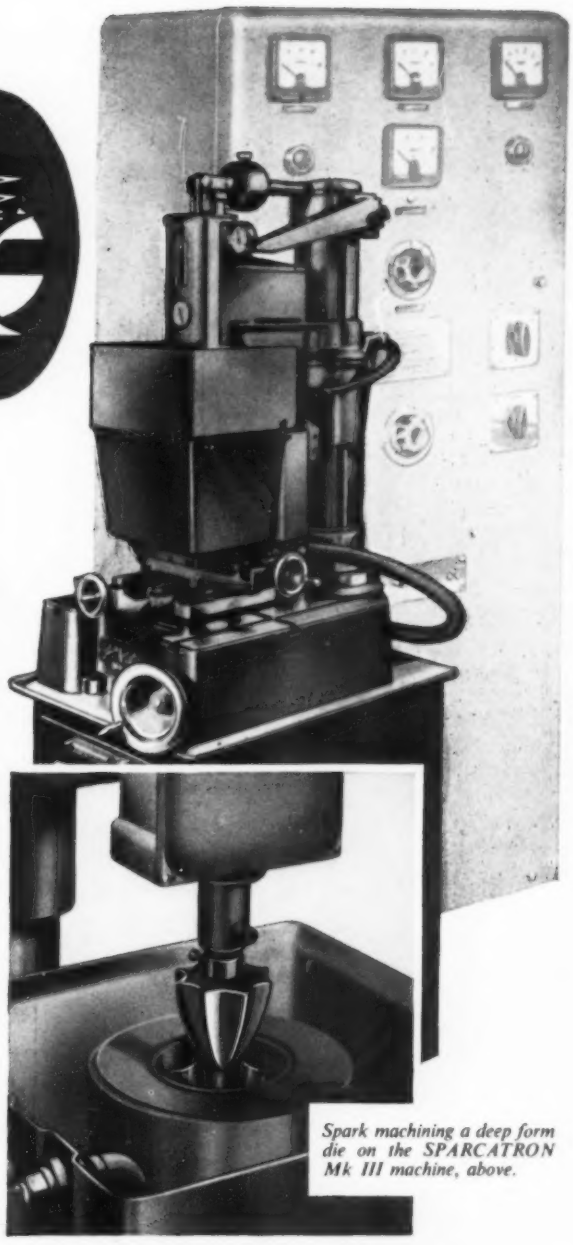


A typical set-up showing a milling cutter undergoing the SPARCARD surface hardening treatment.



Spark machining a deep form die on the SPARCATRON Mk III machine, above.

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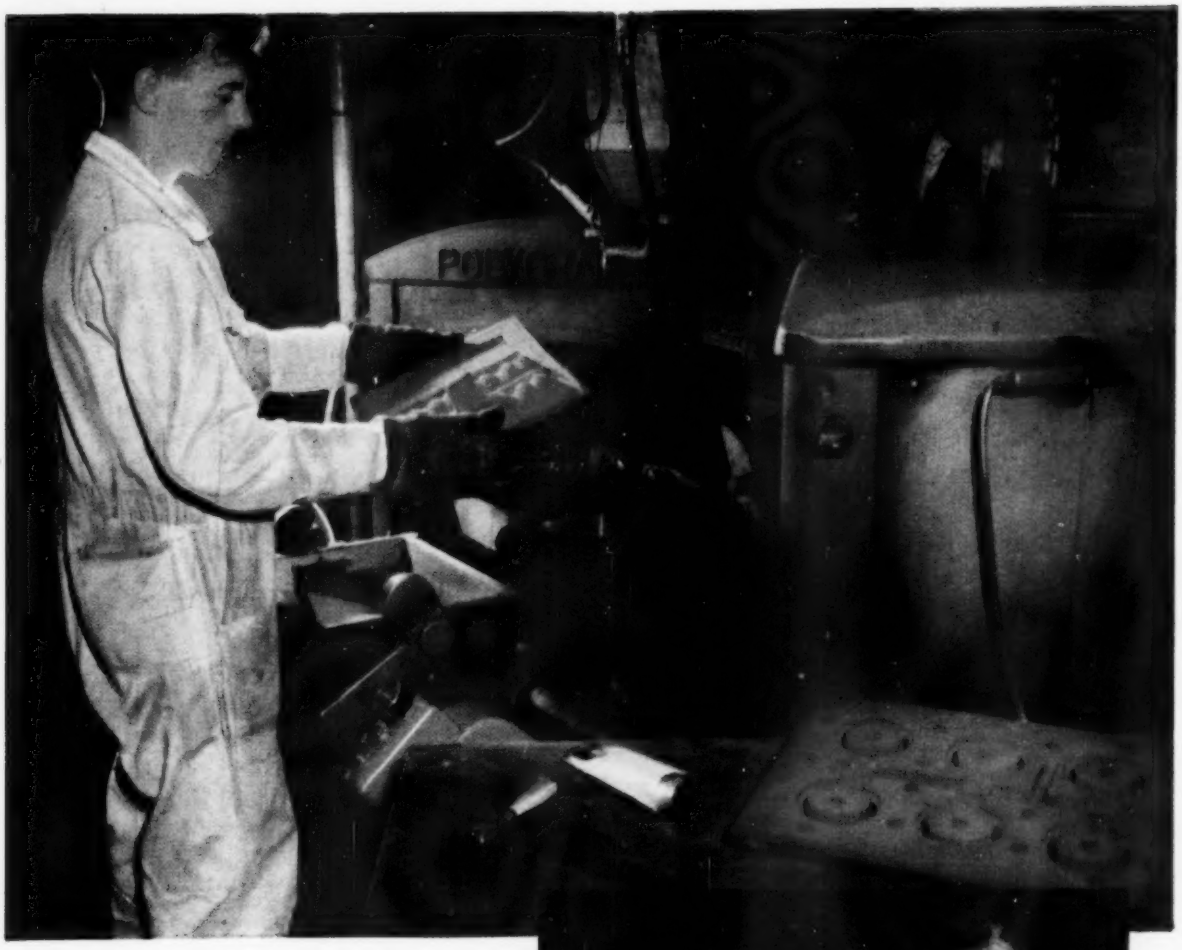

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